

CHARACTERIZING ACCUMULATED OXIDATION POND BIOSOLIDS AT THE  
ARCATA WASTEWATER TREATMENT FACILITY

By

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## ABSTRACT

### CHARACTERIZING ACCUMULATED OXIDATION POND BIOSOLIDS AT THE ARCATA WASTEWATER TREATMENT FACILITY

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Oxidation ponds (OPs) are a natural wastewater treatment system that have been used internationally for their low maintenance, cost, and technology characteristics. The City of Arcata has relied on the performance of their two oxidation ponds for the past 50 years to meet National Pollutant Discharge Elimination System (NPDES) discharge permit requirements. However, during specific times of the year and after decades of operation and minimal maintenance, these oxidation ponds serve as a source of solids and nitrogen that create stress for downstream components of the system. As biosolids have accumulated, the hydraulics of the OPs have deteriorated and the effects of stored pollutants such as ammonia and suspended solids have started acting as an internal load that the downstream system has to remove. As a result, the Arcata Wastewater Treatment Facility (AWTF) is exploring options for biosolids remediation during its facility upgrade.

The objective of this project was to characterize the accumulated biosolids for OP1 in three different ways. First, a spatial analysis and inventory was done using a field sample survey and ArcGIS to determine the biosolid volume, mass accumulation, and spatial distribution within OP1. Second, the composition of the biosolids was explored

using standard analytical procedures to determine what and how much of regulated pollutants are deposited in OP1. Lastly, the treatability of the biosolids was tested using a series of simple aeration experiments that were operated with roughly 6-ft<sup>3</sup> of a solids/water slurry that mirrored the conditions in OP1. Aeration was tested because it was the primary treatment option considered by the AWTF.

The results of the characterization process revealed that nearly 40% of the OP1 volume is occupied by wet biosolids with the most impacted areas being located at the inlet and outlet borders of the pond. The mass of these stored solids (approximately 11,416,000 lbs) is roughly equivalent to the solids load that the AWTF would receive over more than eight years of operation. These stored solids contain significant masses of nitrogen (325,000 lbs: estimated to more than one-year worth of AWTF influent nitrogen mass) and other high oxygen demanding substances. Over 1.5 million lbs of dissolved oxygen would be required under a best-case scenario to aerobically treat this mass of nitrogen alone.

The results of these characterizations support the need for solids remediation of some form in OP1. The accumulated solids are occupying volume that could be used for operational storage and the integration of stored pollutants into the bulk water volume is creating a strain for the treatment systems downstream of OP1. Aeration that both provides oxygen and keeps the biosolids suspended is recommended along with the need for the development of best operating procedures should aeration equipment be installed.

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## ABBREVIATIONS AND ACRONYMS

AMRI – Arcata Marsh Research Institute

AWTF – Arcata Wastewater Treatment Facility

BOD – Biochemical Oxygen Demand

CBOD – Carbonaceous Biochemical Oxygen Demand

COD – Chemical Oxygen Demand

DO – Dissolved Oxygen

GIS – Geographic Information System

GPS – Global Positioning System

IDW – Inverse Distance Weighting

ISE – Ion Selective Electrode

NBOD – Nitrogenous Biochemical Oxygen Demand

$\text{NH}_3/\text{NH}_4^+/\text{NO}_3$  – Ammonia/Ammonium/Nitrate as N

NPDES – National Pollutant Discharge Elimination System

OP, OP1, OP2 – Oxidation Pond, Oxidation Pond 1, Oxidation Pond 2

OPBS – Oxidation Pond Biosolids

PCS – Projected Coordinate System

SBOD – Soluble Biochemical Oxygen Demand

SMD – Solids Measuring Device

TKN – Total Kjeldahl Nitrogen

TSS – Total Suspended Solids

## INTRODUCTION

Oxidation ponds are one of the most widely used wastewater treatment technologies in the United States. The low-technology, low-cost, and ease of use of oxidation ponds are the primary reasons why approximately 40% of treatment facilities within the United States depend on them for meeting secondary treatment standards for wastewater treatment and reuse (WEF 1998). This holds especially true for low-income communities that rely on ponds to treat their wastewater to regulatory standards. The processes behind pond treatment have been studied for decades but two issues are increasing the need to better understand pond performance and adapt new management procedures.

First, wastewater discharge regulations have become stricter as the effect of treated wastewater on receiving waters has been studied. When the Clean Water Act was introduced in 1972, the first iteration of the National Pollutant Discharge Elimination System (NPDES) permits only required monitoring biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform (EPA 1973). Forty years later, the range of analytical techniques, monitoring technologies, and treatment options has increased drastically. In addition to the original three constituents, current NPDES permits typically assign discharge limits for the concentration of ammonia, chemical oxygen demand (COD), and many other pollutants. While some treatment facilities can adapt more easily to changing regulations, resource- or income-limited communities may find it more

difficult to meet these new standards. Therefore, understanding the processes and treatment options for existing low-cost systems is imperative.

The second issue concerning pond treatment is a result of their natural processes and operation. Oxidation ponds are designed as a facultative system that utilizes algae to reduce the TSS and BOD of influent water. This is achieved by natural physical and biological processes that actively accumulate biosolids over decades of use. Gravity settled solids make up the most obvious portion of these biosolids but the deposition of decaying flora and fauna ('living' component) contributes as well.

Previous research shows that these accumulated biosolids can affect treatment in multiple ways. This additional 'source' of stored pollutant mass can cause a pond to appear to have reduced treatment efficiencies. Any reduction in perceived treatment efficiency is critical to communities who may face significant fines due to discharge permit violations.

The objective of this project is to research current characterization and treatment methods for oxidation pond biosolids (OPBS) and perform pilot-scale testing using OPBS from the Arcata Wastewater Treatment Facility (AWTF) in Northern California. This project includes physical testing and characterization of OPBS at the AWTF in an effort to expand on and implement previous research in a setting that relies on an oxidation pond system to meet discharge permit requirements. The impacts of OPBS have become an issue at the AWTF as the City of Arcata is in the process of upgrading their facility while also negotiating terms of a new regulatory discharge permit with the California State Water Resources Control Board. With both an upgrade and a new permit



looming, greater attention is being placed on every treatment process. This includes the two oxidation ponds which have been operating without biosolids maintenance for the past 50 years.

For the purposes of this project, the first of the two oxidation ponds (OP1) at the AWTF is the project site (Figure 1). OP1 is a 24-acre facultative pond that has had time-intermittent aeration, primarily for odor control. A more thorough understanding of the AWTF OPBS is desired to determine possible treatment options for the facility upgrade.

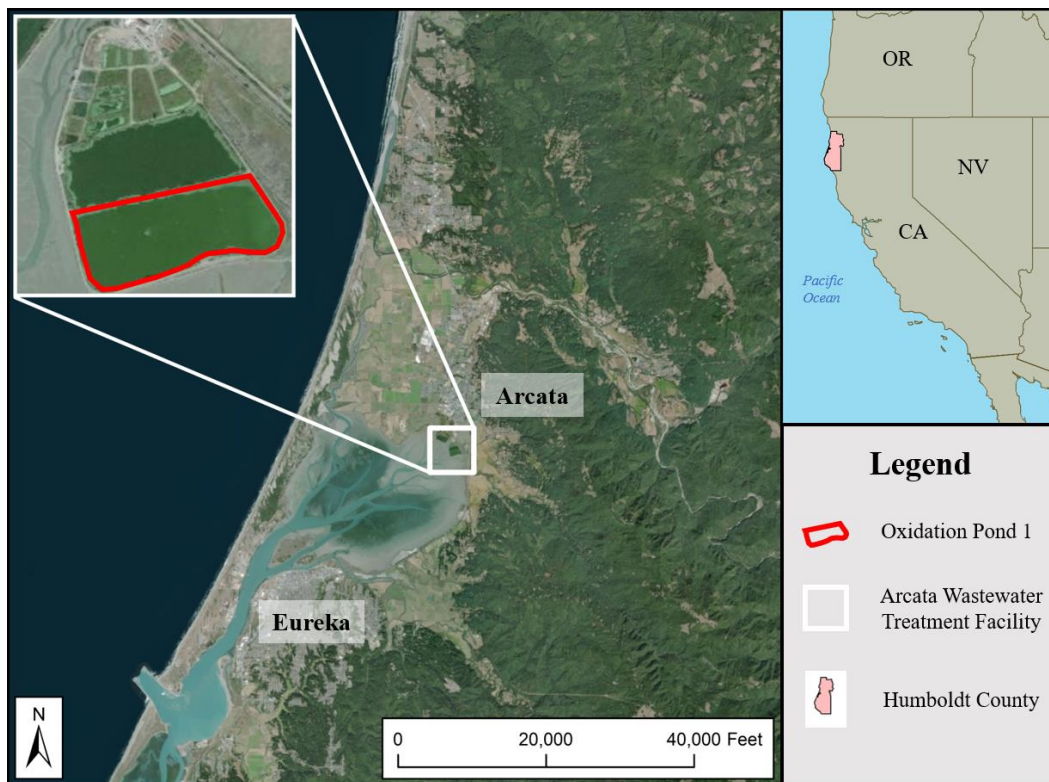


Figure 1. Project locator map. OP1 is the first of a two-pond series at the Arcata Wastewater Treatment Facility in Arcata, CA. Map imagery courtesy of ESRI.

## REVIEW OF LITERATURE

Research on oxidation pond performance has been documented since the 1960s. Hydraulics, treatment capabilities, and OPBS accumulation have been analyzed for many pond systems in many climates. This review of literature focuses on information regarding how OBPS accumulate, how they are distributed within OPs, what their biogeochemical composition is, and how to effectively treat or reduce them. The purpose of this review is to determine potential characterization and treatment methods, how site specific OPBS are, and if there can be any expected trends regardless of location.

Accompanying this general review will be a more detailed review of the Arcata Wastewater Treatment Facility. Details about the construction, operation, and loading of the AWTF must be known to use the AWTF as an illustrative example of OPBS characterization. Literature provided by the Arcata Marsh Research Institute (AMRI) is used to determine loading and accumulation data.

### Spatial Distribution and Measurement Techniques for OPBS

OPs remove solids through gravity settling and long hydraulic residence times. While this may be their designed settling objective, OPs experience other instances of settling due to their climate, incorporation of aerobic and anaerobic bacteria, and flocculant and discrete settling. Strong winds, high flows, bacterial mats, and anaerobic gas production may cause settled material to be resuspended and move down-pond before

resettling (EPA 2011; Keffala et al. 2013). Seasonal flora and fauna senescence also contribute to the solids within a pond. These fresh, organic solids may be deposited in hydraulic dead-zones or throughout the primary flow path of the pond depending on the life stage of the flora and fauna. Knowing how these solids are distributed and how much volume they occupy is an important first step in OPBS characterization. To do this, the methods of measuring and mapping the OPBS must be explored. Regardless of the collection method used, length, width, and height measurements are used to estimate OPBS volumes (Papadopoulos et al. 2003; Nelson et al. 2004; Abis and Mara 2005; Picot et al. 2005; Keffala et al. 2013).

#### Methods of OPBS measurement

There are multiple techniques to measure the accumulated OPBS. In this section, a brief discussion of spatial sampling is included along with three detailed options of depth measurements are discussed (manual, optical, and automated).

Methods of spatial sampling can be as simple as flags placed in the ground and as complex as differential global positioning systems (GPS). For this project, when a “simple grid” is mentioned, the documented methods include procedures that involve the use of manual markers such as flags or digital waypoints. The manual creation of grid/sample points through physical flagging or digital marking requires users to navigate to specific coordinates. “Advanced” spatial mapping techniques involve the automatic logging of spatial data using more sophisticated GPS systems. Either spatial sampling technique can be implemented for any depth measurement method, but typically more sophisticated spatial methods are paired with more sophisticated depth measurements.

Manual measurement method. The most common and cost-effective method of measuring OPBS is using a manual depth measurement system along with a simple grid system (Keffala et al. 2013). There are many different versions of a manual depth measuring device. Some rely on the capture of the OPBS, while others rely on solids staining the measurement device, and others rely on resistance. However, even with the differences, each type of manual device relies on the same principal of physical collection and measurement using a graduated rod.

A well-known example of the capture type of device is the Sludge Judge, a translucent pipe that relies on a ball valve to open the sampling port and then seal it using the resistance of the collected sample (Figure 2). The Sludge Judge is an effective method of measuring samples that are less than approximately 5% solids (Cole-Parmer, unpublished material, 2019). Higher solids concentration samples are too viscous to be trapped and will clog the entrance of the device.

An example of a staining, manual method is the “white towel” test, another popular method of depth measuring due to its ease of use and availability (Malan 1964; Pearson et al. 1987). This method involves wrapping a white towel along the length of a pole, placing the towel-end into the OPBS, withdrawing the device, measuring the height of the OPBS stuck to the towel, and replacing the towel for the next measurement (Figure 3). This sampling method is effective at measuring viscous solids but has an increased error when dealing with high moisture solids due to the solids being washed away upon retrieval (Abis and Mara 2005).

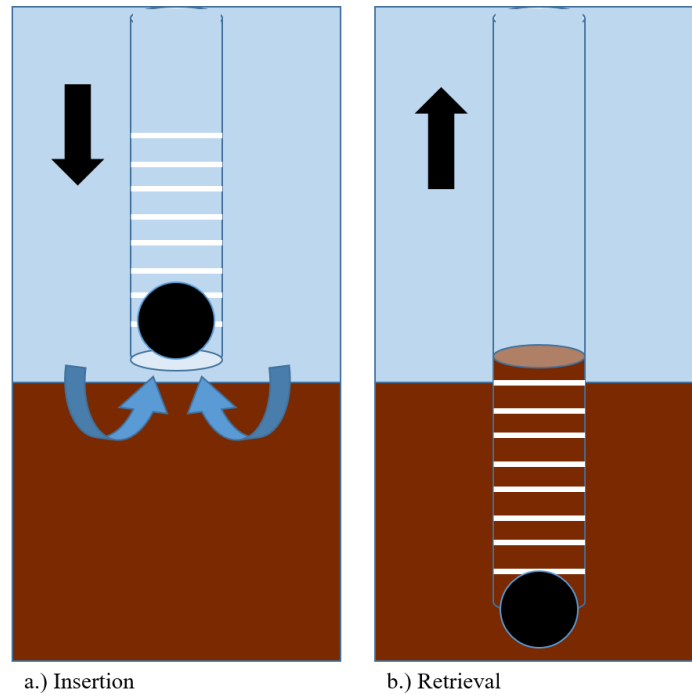


Figure 2. Illustration of how a Sludge Judge works.

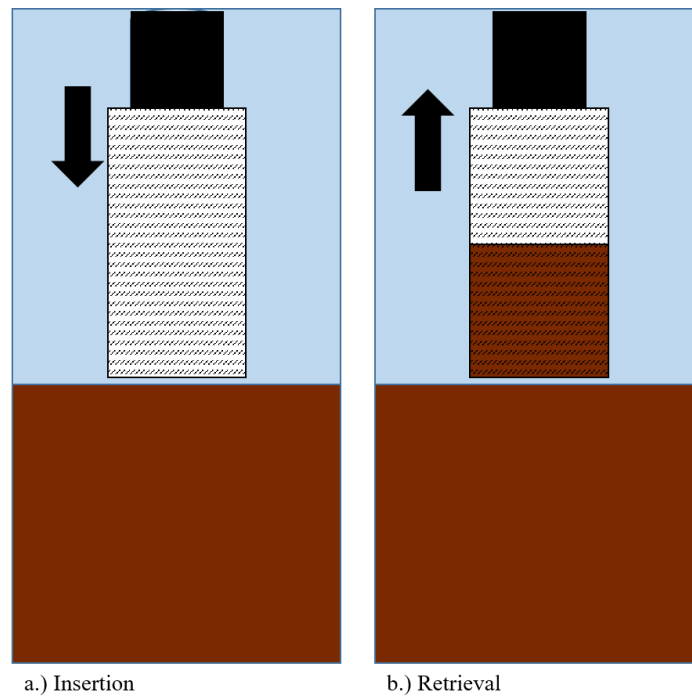


Figure 3. Illustration of the white towel test.

An example of a resistance-based sampling device is a custom sampler created by AMRI (Figure 4). This device utilizes a two-rod system where one rod has a fine-screen mesh (solids basket) that allows water to pass through it but not solids (AMRI 2008). Upon contacting the solids layer, the rod that has the attached mesh is held at the solids height while the second rod continues to the bottom depth. Like the staining method above, it is difficult to accurately measure loose solids with this device, due to them passing through the mesh.

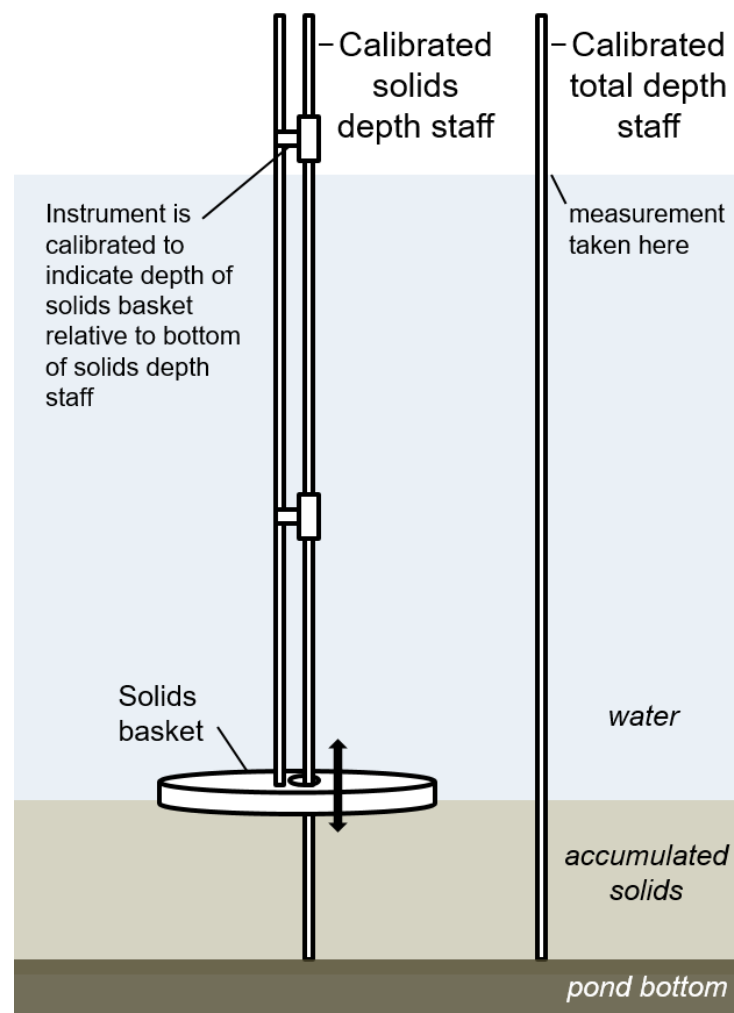


Figure 4. Illustration of the AMRI resistance sampler (AMRI 2008).

Optical measurement method. The next method of OPBS measurements, optical sensing, is a combination of the manual measurement devices coupled with remote sensing technology. Optical sensing relies on a simple grid method along with a graduated rod. However, the method to determine the depth is automated using an optical sensor that detects light and signals to the user when that light is no longer measurable (Figure 5). Nelson et al. (2004) successfully used an optical measuring device to map several OPs in Mexico. The use of an automated detector increases the speed at which samples can be measured but comes with a slightly higher price due to the component pieces. Also, while it is being phased out in the presence of more reliable measurement methods, optical methods such as Secchi disks have been reported to be used to estimate total and OPBS depth (Picot et al. 2005).

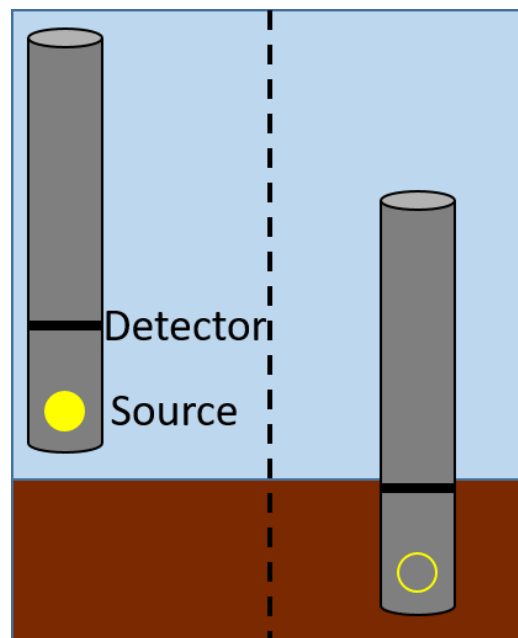


Figure 5. Illustration of an optical sensing measurement device.

Automated method. The last measurement method is the most sophisticated of the three and has been paired with advanced spatial sampling techniques to create a fully automated sampling procedure. Automated sonar devices are used to detect vertical depths while spatial coordinates are simultaneously recorded. For example, Jupsin et al. (2009) created a custom program to collect spatial and depth measurements every second, creating a high-resolution solids map. However, depth measurements using automated sonar equipment requires some method of differentiating between solids depth and total depth. If the pond being measured has a constant depth, then there is no concern because the only recorded measurement would be the solids depth.

#### Methods of OPBS mapping and analysis

With the advancement of geographic information system (GIS) software such as ArcGIS and QGIS, mapping has become a quick and flexible process. While creating maps is relatively easy, it is important to understand the methods in which data is interpolated and used in its creation. For this review, only two methods will be discussed due to their popularity and differences in complexity: the inverse-distance weighting (IDW) interpolation method and the Kriging method. Before addressing these, it is important to note that both methods are dependent on the collected spatial data being spatially correlated. A statistical test, such as the Global Moran's I autocorrelation test, should be used to check for data randomness. If the data is shown to be clustered (not randomly distributed), then it is spatially correlated, and it is valid to interpolate.

IDW interpolation is a relatively simple method of estimating values between points. The method assigns values to intermediate points by linearly scaling the value of a



nearby data point relative to its distance (ESRI 2018a). The farther a point is from a measured data point, the less like that measured point it is. This simple relationship is both the positive and the negative for the method. Because it only relies on distance, no additional information is required to create the interpolation surface. However, for the same reason, IDW has the chance to misrepresent a dataset. Since no statistical information is used, the accuracy of the method is dependent on the resolution of the sampling (Setianto and Triandini 2013).

Kriging interpolation is a calculation intensive method that attempts to account for overlying geostatistical patterns and trends within the dataset (ESRI 2018b). By accounting for variance between points, the Kriging method can infer patterns in clusters of sample points rather than only relying on a distance-decaying relationship like IDW. This use of geostatistics makes Kriging a powerful tool but it also limits its application to users who are knowledgeable about its processes.

Setianto and Triandini (2013) did a comparative analysis between the two methods and while they concluded that the Kriging method was the more accurate, the IDW was not far behind. This is because the results of any interpolation method are dependent on the density of sample points (distance between samples). Interpolation error decreases as the distance between sample points decreases. Setianto and Triandini (2013) concluded that the IDW method is more intuitive in its application which should be a consideration for which method to use at a given OP's facility. Another conclusion from the study was that the consistency of the sampling grid shape is important regarding accuracy. Literature studies that use interpolation in OPs tend to favor the Kriging

method (Nelson et al. 2004; Picot et al. 2005; Jupsin et al. 2009), however, there is no discussion as to why this method was preferred.

### Distribution patterns of OPBS

Given many different environments, sampling methods, and analysis methods, there appears to be some general trends in the distribution patterns of biosolids in OPs. OPs from Brazil, France, Greece, Mexico, Tunisia, the United Kingdom, and the United States all show a pattern of accumulated solids at both their inlet and outlet structures (Schneider et al. 1984; Papadopoulos et al. 2003; Nelson et al. 2004; Abis and Mara 2005; Picot et al. 2005; Jupsin et al. 2009; Passos et al. 2014; Chalatsi and Gratziou 2015). More detailed mapping studies indicate the potential for accumulation in hydraulic dead-zones. While the general inlet/outlet pattern is observed, there are differences in accumulation between each of the study ponds. For example, the four OPs in Mexico discussed in Nelson et al. (2004) all vary in their distribution patterns. One of the OPs has a near even distribution while another only has large accumulation at the inlet and outlet along with noticeable mounding at central points in the pond. So, while general trends seem to be predictable, location specific information is still preferred.

### Constituents and Biogeochemical Characterizations of OPBS

The composition of OPBS is as important as the volume of the OPBS. Knowing the primary components of the OPBS, and their concentrations, leads to a better understanding of how to treat them and the potential impact on performance of the OP.

OPs are a natural treatment system that rely on microbial flora and fauna to treat the influent wastewater. Influent solids as well as the resulting solids from the natural system contribute to the total volume of OPBS. The complex system of biogeochemical cycles that are constantly in action determine how contaminants in these OPBS are transformed or removed. To add to the complexity, these natural cycles are not happening in a static environment, but instead in a dynamic reactor meaning that different steps of a given transformation process may vary based on time, location, available resources, and several other factors (Webster and Patten 1979). Similar to the resuspension mentioned in the previous section, biogeochemical cycles are expected to play a role in OPBS composition and spatial variation.

The primary issue with characterizing the composition of the OPBS is determining what contaminants should be monitored. With nutrients, metals, and organic contaminants commonly being monitored for compliance in the U.S., there is a very long list of analytical tests that could be performed. Having a better understanding of OPBS constituents of concern identified in the literature along with the characterization processes discussed will allow for a better general characterization that may avoid an expensive suite of analytical tests.

As with spatial characterization, the literature regarding OPBS composition characterization is varied depending on location, influent characteristics, and site history. However, several constituent families of concern are commonly tested, including the solids themselves (suspended, volatile, and total), nitrogen (ammonia, nitrate, and organic), biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and

heavy metals (Schneiter et al. 1984; Al-Ghusain et al. 2002; Papadopoulos et al. 2003; Nelson et al. 2004; Banks et al. 2005; Racault and Boutin 2005; Melidis et al. 2010; Mtshali et al. 2014). Less common constituents included chlorophyll, phosphorus, coliforms, and other indicator organisms like helminths.

#### Total and volatile solids

Total solids are the defining characteristic of OPBS and measuring the concentrations and volume accounts for the true mass of the OPBS. Solids within OPs originate from the influent wastewater as well as the produced organic solids from the resident flora and fauna communities. The standard method of measuring the total and volatile solids is a gravimetric method. Separating the total solids into fixed and volatile components can reveal what fraction of the OPBS is theoretically digestible (Andreoli et al. 2007). Biological treatment is less effective for non-volatile solids, leaving removal strategies the only treatment method. However, volatile solids are not necessarily easily digestible. Recalcitrant material, like cell walls from detrital material, may resist digestion even though they are carbon based (Yen and Brune 2007).

Literature values for the percent of OPBS total solids that are volatile vary greatly with values as low as 29% and as high as 93% (Schneiter et al. 1984; Papadopoulos et al. 2003; Picot et al. 2005). Additionally, Papadopoulos et al. (2003) noted distinct layers in the accumulated solids within an anaerobic pond. They found that the bottom layer of solids was more compacted, had a lower moisture content, and a lower volatile component when compared to the “fresh” top layer of solids. This confirms that solids composition can be spatially variable with depth.

## Nitrogen

Nitrogen is one of the most abundant elements on Earth and it is one of the most essential biological building blocks. For wastewater applications, the starting point for the nitrogen cycle is usually organic nitrogen and ammonia ( $\text{NH}_3$ ) or ammonium ( $\text{NH}_4^+$ ) originating from human waste (Metcalf & Eddy 2003). In agriculture-dominated areas, the influent nitrogen source may be more skewed towards nitrate as a result of fertilizer runoff.

An understanding of the transformation processes is required to properly address issues of nitrogen build-up in wastewater systems. The nitrogen cycle is the grouping of biogeochemical processes that transforms nitrogen from biologically unavailable gas (nitrogen gas or nitrous oxide) to biologically available organic and inorganic forms (amino acids, ammonia, nitrite, and nitrate) and vice-versa (Figure 6).

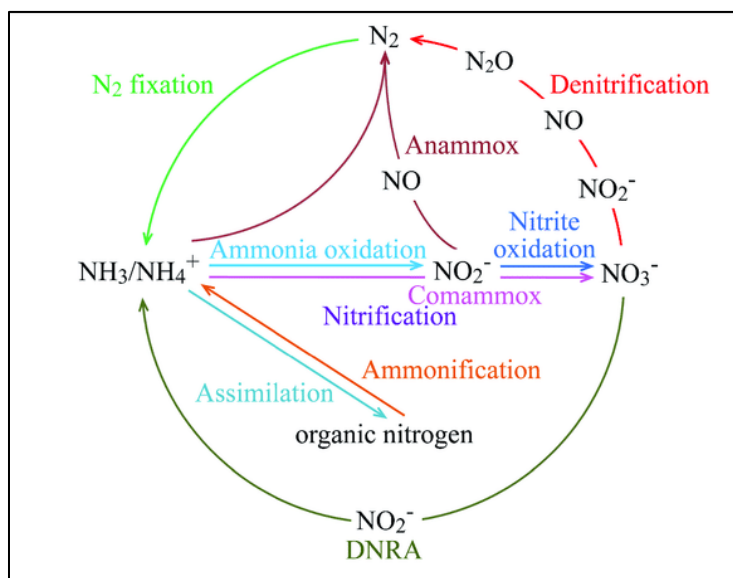
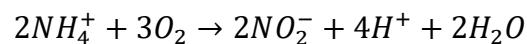


Figure 6. Nitrogen cycle (Dang and Chen 2017).

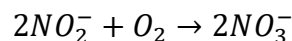
Mineralization. The nitrogen cycle relies on decomposing organisms to aid in the recycling process of nitrogen. Mineralization is the conversion of organic nitrogen to ammonia. Flora and fauna intake nitrogen in many forms, ranging from simple inorganic ammonia and nitrate to more complex amino acids of organic nitrogen, and incorporate it into their own cell tissue. In oxidation ponds, once these organisms die and settle to the bottom, their detrital material accumulates over time and begin to form solids layers. This detrital material contains stored nitrogen in the form of organic nitrogen. Over time, and in favorable conditions, decomposing organisms process the organic nitrogen stored in the solids and releases nitrogen back into the water column in the bioavailable form of ammonium.

Nitrification. Nitrification is a two-step process that relies on two genera of oxidizing bacteria. In the first step, Nitrosomonas oxidize ammonium to nitrite aerobically in the following stoichiometric process (Metcalf & Eddy 2003):

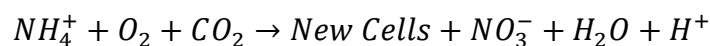


Nitrogen does not exist in the nitrite form for long. Nitrite is easily oxidized and transformed to the more stable nitrate by the second oxidizing bacterial group,

Nitrobacter:

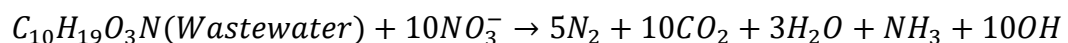


The above stoichiometric process can be combined along with estimates for the biological growth to produce the overall reaction (Metcalf & Eddy 2003):



Accounting for mass requirements, approximately 4.25 lbs of oxygen are required to convert every 1 lb of ammonium to nitrate (4.6 lbs for total Kjeldahl nitrogen to nitrate) (IHS n.d.). This process requires 0.08 lbs of carbon dioxide and produces approximately 0.16 lbs of new cell material. The final component of this equation is the produced hydrogen ion and the acidic conditions it creates. Nitrification operates best at a pH range between 6.8-8.0 and experiences significant decreases in reaction rates below 6.8 (Metcalf & Eddy 2003). So, one of the products of nitrification (hydrogen ions) actively inhibits further nitrification by reducing the pH outside of the optimal range. To combat this, the alkalinity of the treatment volume must be maintained. Approximately 7.14 lbs of alkalinity (in the form of calcium carbonate ( $\text{CaCO}_3$ )) is required per 1 lb of ammonium converted. With nitrogen now in the nitrate form there are several further transformation process pathways it can follow.

Denitrification. Denitrification is a blanket term that encompasses all transformation pathways of nitrate and can be the primary nitrogen removal mechanism during winter months (Camargo Valero et al. 2010). The most common denitrification process considered for wastewater is dissimilating nitrate reduction, which converts nitrate to inert nitrogen gas (Davis 2010). In this process, nitrate is used as the electron acceptor for a bacteria's anaerobic respiration. The stoichiometric reaction is shown below (Davis 2010):



Both anaerobic and facultative bacteria are responsible for this type of denitrification. In a facultative oxidation pond this process occurs from the border of the

photic zone to the pond bottom where anaerobic conditions exist. Once converted to the gaseous form, nitrogen is removed from the system. In some instances, the dissimilating reduction process is altered to produce ammonium from the reduction of nitrate. This process keeps nitrogen in the pond by immediately cycling nitrate back into the bioavailable ammonium form.

Another primary denitrification process in oxidation ponds is assimilatory nitrate reduction which occurs when the flora and fauna of the pond uptake nitrate as a nutrient source. This process can only occur in situations with high concentrations of nitrate and low concentrations of ammonia due to the preferential uptake of ammonia (Davis 2010).

Other nitrogen transformation processes. The three nitrogen cycle pathways described are the most common processes in wastewater, however there are multiple other branches of the nitrogen cycle that are potentially in effect at any time. Processes like anammox (the direct, aerobic oxidation of ammonium to nitrogen gas) may be in effect but to an unknown degree.

Ammonia uptake by flora and fauna is also common and can make a significant difference in ammonia concentration during growing seasons. This uptake only acts as a temporary storage however, since cells senesce and deposit their stored nitrogen at the bottom of ponds or in the downstream portion of wastewater treatment. Uptake by the flora can be the largest, temporary removal pathway depending on the season (Camargo Valero et al. 2010). Once the flora die, the OPs receive a load of stored nitrogen and carbon as organic nitrogen and organic carbon. As both types of organic compounds



decay they release amino acids and dissolved organic carbon that can be used by another organism.

Ammonia volatilization is another removal mechanism for nitrogen. The pKa of ammonia (where 50% of ammonia is in the gaseous  $\text{NH}_3$  form) is 9.25. If the pH of the water column becomes high enough, most of the ammonia exists in the gaseous form and can either be naturally dispersed to the air or mechanically agitated for a quicker release.

Nitrogen concentrations in OPBS. Most of the literature includes measuring ammonia and nitrate using either an ion selective electrode or a colorimetric method. For the organic nitrogen, a Kjeldahl test is done to digest and convert the organic material into the ammonia form. OPBS nitrogen (in any form) is most commonly reported in mg/L units which does not allow for a comparison or relationship directly to the OPBS themselves. However, a few studies have used a percent or mass/mass unit that allows for comparison. Namèche et al. (1997) measured total nitrogen content in two ponds biosolids to be approximately 1% (10,000 mg-N/kg-dry OPBS), with an ammonia fraction of only 0.005% (50 mg-N/kg-dry OPBS). Schneider et al. (1984) measured OPBS with total Kjeldahl nitrogen concentrations between 1.4-3.4% and ammonia fractions between 0.09-1.1%. A more recent solids study in Swaziland, Africa (Mtshali et al. 2014) found OPBS with total nitrogen fractions between 0.5-4.5%.

#### Oxygen demand

The biochemical oxygen demand (BOD) is the amount of dissolved oxygen (DO) required for biological processes in a water system. DO is required for many processes including cellular respiration, oxidation of ammonia to nitrate, and decomposition of

organic material. DO is the critical factor for receiving waters while BOD is the measurement of the pressures related to oxygen on the system. A large value for BOD is indicative of a potentially harmful biological environment, where there may not be enough dissolved oxygen to meet this demand. In those instances, the water becomes anaerobic and dominant facultative bacteria convert to anaerobes.

The norm for BOD measurements is to monitor the initial and final dissolved oxygen (DO) concentration of a sample over a 5-day period. The reduction of DO over the 5-day period is referred to as the BOD<sub>5</sub> (BOD for this report). The literature reviewed for this paper reports BOD concentrations in the more common mg/L unit, with no paper using a percent or mass/mass unit.

While the BOD does not give specific information regarding what is in the water, subtests can be performed to determine the nature of the BOD. The amount of oxygen required for carbon-compound degradation can be estimated using the carbonaceous BOD (CBOD) test. The amount required for nitrogen conversion (NBOD) is generally estimated as the difference between the BOD and CBOD. The NBOD can serve as an approximate measure of the amount of nitrogen in a system. If the concentration of ammonia is known, and using the stoichiometry of the nitrification process, an estimate of other nitrogenous sources can be made. For example, knowing that the NBOD of a sample is 100 mg/L, the ammonia concentration is 20 mg/L, and the oxygen required to convert ammonia to nitrate is approximately 4.25 mg O<sub>2</sub>/mg NH<sub>3</sub>-N, the theoretical oxygen demand for ammonia conversion is 85 mg/L. This would indicate that the

remaining 15 mg/L expressed in the experimental NBOD could either be another form of nitrogen conversion such as mineralization.

The experimental BOD, CBOD, and NBOD may not be representative of field conditions because they are limited to the 5-day test period. For samples that may contain recalcitrant material, 5 days may not be long enough to express their impact on DO. For instances like this, another test would be required. Either the ultimate BOD or the chemical oxygen demand (COD) could be tested. The ultimate BOD allows the sample to consume oxygen until the DO reaches a critical low point. The COD is larger scale oxygen demand test and captures the oxygen demand for any reaction (chemical or biological). In instances where the BOD is not capturing all the expected demand, the COD can be measured and used to estimate other contributions.

#### Heavy metals

Heavy metals in wastewater are associated with the suspended solids and normally settle out of the water column in OPs and deposit in the biosolids layer. Metals are regulated contaminants due to their behavior as acute toxins to multiple aquatic species. Regarding OPBS, heavy metals are a concern for reuse or final disposal. High concentrations are not allowed in biosolid composting or land application. The most common metals of concern in the literature are: cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc (Schneider et al. 1984; Blais et al. 1992; Fuentes et al. 2007; Melidis 2010). The metals present are largely unique to each OP influent source. Areas may have higher concentrations of metals due to local industry or geology. The metals most likely contained in the influent wastewater should be the largest factor determining

what OPBS metals to analyze due to the standard measuring techniques being costly analytical methods (Blais et al. 1992; Fuentes et al. 2007; APHA 2017).

### Common Treatment Options for OPBS

Determining the composition of OPBS and how they are distributed is an important step to understanding an OP, but just as important is determining what treatment options are available. Ultimately, OPs that are impacted by their solids must be rehabilitated or face the consequences of an increased treatment strain downstream and potential discharge permit violations. Numerous treatment technologies have been developed over the past few decades but, much like the OPBS themselves, determining the best option is location dependent. Three primary treatment options are explored in this section: dewatering and land application, anaerobic digestion for energy recovery, and aerobic digestion by aeration. Other methods of treatment exist and can be explored if none of these options are feasible.

#### OPBS dewatering and land application

One of the most common treatment options in rural, agricultural areas is OPBS dewatering and land application. This process utilizes the byproduct of OP treatment as a resource for nutrient recycling. As noted in the previous section, OPBS still contain nutrients and minerals including nitrogen, phosphorus, organic carbon, and magnesium (Andreoli et al. 2007). Given sufficient disinfection and pathogen deactivation, OPBS can provide a useful resource to local communities as a fertilizer amendment (Hosetti and

Frost 1995). For OPBS to be used for land application, they must be processed and meet local regulatory requirements.

The first step to processing OPBS is to remove them from the OP and remove excess water from the volume. While not all land application options require a minimum solids content, a higher percentage is preferred to reduce transportation costs and to reduce the volume solids being spread (Andreoli et al. 2007). OPBS is usually dewatered to a solid's concentration between 10-45%, with the large variation being due to dewatering techniques. One well-documented case study in France utilized solids pumps and centrifuging to produce a 27% solids content (Picot et al. 2005). While technology can be effectively used for dewatering, there are two case studies that document low-tech options. A different case study in France reported that approximately 10% of surveyed OPs are dewatered by draining and pumping OPBS to a drying bed to naturally evaporate or drain water over a six-month period (Racault and Boutin 2005). Another low-tech method was developed that involved planting local vegetation on drained OPBS. The vegetation consumed the water content (and nutrient resources) which effectively increased the solids content from 12% to 18% (Oakley et al. 2012).

After dewatering, the dried OPBS are required to meet regulatory guidelines involving metals and pathogen concentrations. Each facility is subject to their local regulations but generally if metal concentrations are greater than specified limits, OPBS are not suitable for land application and must be disposed via a landfill as hazardous waste due to the lack of an effective metal removal technique (Oleszkiewicz and Mavinic 2002). Pathogens, however, can be treated to meet standards. Inactivation of coliforms,

salmonella, and helminths is required in the U.S. for land application (EPA 1994).

Dewatered OPBS can be formed into compost piles and heat treated to reduce pathogen concentrations.

Dewatering and land application of OPBS is treatment strategy that utilizes the OP byproduct and its accumulated nutrients as a resource. However, this method is dependent on meeting disposal regulations and having space and a need for an organic soil amendment. For this reason, land application is a less common treatment option for urban environments.

#### Anaerobic digestion for energy recovery

Like land application, anaerobic digestion is another treatment option that utilizes the OP byproduct as useful resource. In many cases, the anaerobic digestion of OPBS is coupled with an energy recovery system to make use of the biogas produced by digestion (Hosetti and Frost 1995; Andreoli et al. 2007). Anaerobic digestion is a common treatment option for facilities that receive large volumes of wastewater (> 10 MGD) but some smaller treatment systems have also reported using anaerobic digesters to treat their facility solids (Oleszkiewicz and Mavinic 2002; Metcalf & Eddy 2003). While the economics of digesters are more favorable for larger facilities, smaller digesters may still be the most cost-efficient treatment for some facilities.

Anaerobic digestion for energy recovery utilizes the same processes that naturally occur at the bottom layer of solids in OPs, however they are environmentally controlled and optimized (Metcalf & Eddy 2003). Anaerobic bacteria will process organic material and reduce the concentration of nutrients and organic carbon (by incorporating it into

their own cells) and produce methane as a byproduct (Metcalf & Eddy 2003). To keep this digestion process continuous and occurring at an optimal rate, the digestion reactor is temperature controlled, completely mixed, and frequently monitored for pH and metal concentrations (Andreoli et al. 2007). The digested solids from this process still require a disposal site. If there is a demand, land application can be used, otherwise the solids can be incinerated or deposited in a landfill depending on regional availabilities. Anaerobic digestion is sensitive to pollutant shock disrupting the microbial communities. So, similar to land application, OPBS that are high in metals should not be used for this process and instead disposed via landfill. However, if the concentration of metals is not high enough to kill the bacteria, anaerobic digestion can reduce the volume of solids prior to landfill disposal.

The byproduct of anaerobic digestion, methane, can either be used as a resource or flared. For the first option, a cogeneration unit can be installed that combusts the produced methane to produce energy for the facility. In many cases, enough energy is produced to keep the digester incubated and to partially offset total facility energy (Hosetti and Frost 1995). If the methane is not utilized, it should be flared, rather than just vented, to reduce greenhouse gas emissions for the facility.

Anaerobic digestion is an effective OPBS reduction and treatment strategy that relies on biological processes. This process can produce a useful byproduct, however the facility utilizing it needs to have sufficient capital and waste to operate. Digestion reactors have a large spatial footprint and require expensive design and construction

(Metcalf & Eddy 2003). Cogeneration units also require technical competence and capital. Typically, large urban facilities can best utilize anaerobic digestion.

### Aeration

Aerobic treatment of OPBS involves providing additional oxygen to the system to encourage aerobic digestion of the solids. Unlike the other two methods mentioned above, aeration treatment can occur in-situ or in separate reactors. Facultative ponds already rely on aerobic bacteria to treat their influent water, introducing excess air assists this process while also allowing aerobic activity in the normally anaerobic bottom solids layer. Another benefit of aeration is that the agitation from mechanical mixing keeps the OPBS suspended. This suspension of OPBS provides bacteria access to contaminant loads that would otherwise be trapped in the solids layer. This increased access provides more opportunities for digestion and thus further treatment.

With additional dissolved oxygen becoming available, microbes within the OP or reactor can reproduce at a higher rate which strains their nutrient uptake (Andreoli et al. 2007). When the easily available soluble nutrients are exhausted, the microbes are forced to digest the OPBS to survive. During this digestion, the bacterial community preferentially degrades carbonaceous material to include in their own cellular structure (Metcalf & Eddy 2003). As a result, BOD is reduced at the cost of additional suspended solids in the form of bacteria and disturbed solids. Once BOD is limited, nitrification can begin its process of converting ammonia.

Aeration can be particularly effective for the purpose of nitrogen conversion and removal. Several studies have shown that both intermittent and constant aeration is an



effective method of nitrogen removal (Pollice et al. 2001; Al-Ghusain et al. 2002; EPA 2011) and OPs with aeration tend to have lower ammonia concentrations than their anaerobic counterparts (Schneider et al. 1983; Archer and O'Brien 2005). Aeration scheduling in OPs can be flexible depending on need regarding contaminant removal or climate. For example, given sufficient alkalinity, constant aeration allows for a continual conversion of ammonia to nitrate, which in turn creates an opportunity for ammonia to be reintroduced to the bulk volume via the solids (Rodrigues et al. 2015). Alternatively, if alkalinity is an issue, a time-intermittent aeration schedule would be beneficial. Al-Ghusain et al. (2002) found that a 50% (time on/off) aeration schedule allows for sufficient nitrification and denitrification to occur that recycles the deposited alkalinity.

Like anaerobic digestion, aeration does not completely remove the OPBS, it only reduces the concentration of its contaminants and reduces the total solids contents. However, because aeration can happen on-site, the solids will remain in the OP or a downstream component/clarifier. If contaminant concentration is a more important factor than pond volume/hydraulics, then leaving solids in the treatment system may be cost-preferred. The primary drawback of aeration though, is that the mixing and resuspension of the OPBS destroys any formed flocculent masses. This increases the amount of pore space in the solids slurry and increases the water content, which would make dewatering for disposal more costly.

### Arcata Wastewater Treatment Facility

The facultative pond system at the AWTF was constructed in Arcata Bay in 1957 (City of Arcata 2018). Using historical aerial photos, as well as personal communication, it appears that the dikes along the western and south-western edges of OP1 were constructed by excavating material from within the pond boundary (Figure 7) (Caltrans 1958). This is thought to have resulted in the creation of deep borrow pits along these borders. Data regarding OP grading during construction is not available and may not have been recorded. Besides the construction of the dikes and the inlet/outlet structures, there was no other material added to the OPs. As a result, the OP system relies on the low hydraulic conductivity of the natural clay liner instead of geotextile liners.



Figure 7. Aerial photo of AWTF during construction (Caltrans 1958).

OP1 receives wastewater that has passed through primary treatment (bar racks, grit chamber, and primary clarifier) during normal operations but during high flow scenarios it receives raw influent wastewater with no prior screening. The average flow for OP1 is about 2 MGD but can vary from below 1 MGD to more than 15 MGD (AMRI n.d.). For nearly the first thirty years of OP1 operation, water moved from north to south and then was discharged into the bay. In 1986, the flow pattern was altered to be from east to west to redirect the water to treatment wetlands and a disinfection process. This

east to west flow pattern has been in effect since 1986 with no other changes in flow direction.

OP1 experiences seasonal die-off from its bacterial and algal components due to the local Mediterranean climate. As a result, there are noticeable spikes in ammonia, which are believed to cause coinciding spikes in BOD, during the transition from summer to winter (Figures 8 and 9). The exact mechanism for the ammonia release is unknown, but the major hypothesis from AMRI is that pond turnover caused by differential water temperatures mixes the internal load of nutrients stored in the OPBS into the bulk water volume and increases anaerobic digestion. During ammonia spikes AMRI has noted large quantities of floating biosolids that are suspended by gas formation from the increased digestion. Besides the seasonal spikes, long-term loading trends for BOD and TSS have also been calculated (Figures 10 and 11) (Finney, unpublished data, 2018). Starting in 1988 (when continuous data collection began), BOD has been accumulated in, or has been transformed in, OP1 at a rate of approximately 400 kg/year. Using flow data and concentration in and out of the pond, there has been approximately 4 million more kilograms of BOD have entered than have left OP1. It is important to note that this analysis does not account or track any one BOD removal process but is instead a potential net accumulation estimate. Looking at TSS, however, there is not a net removal of solids. Instead, solids have been produced in OP1 since around 1996. The direct result of this net production is that the downstream treatments systems are under more stress to remove another pollutant load. This accumulation also confirmed that the OP system at the AWTF is solids strained.

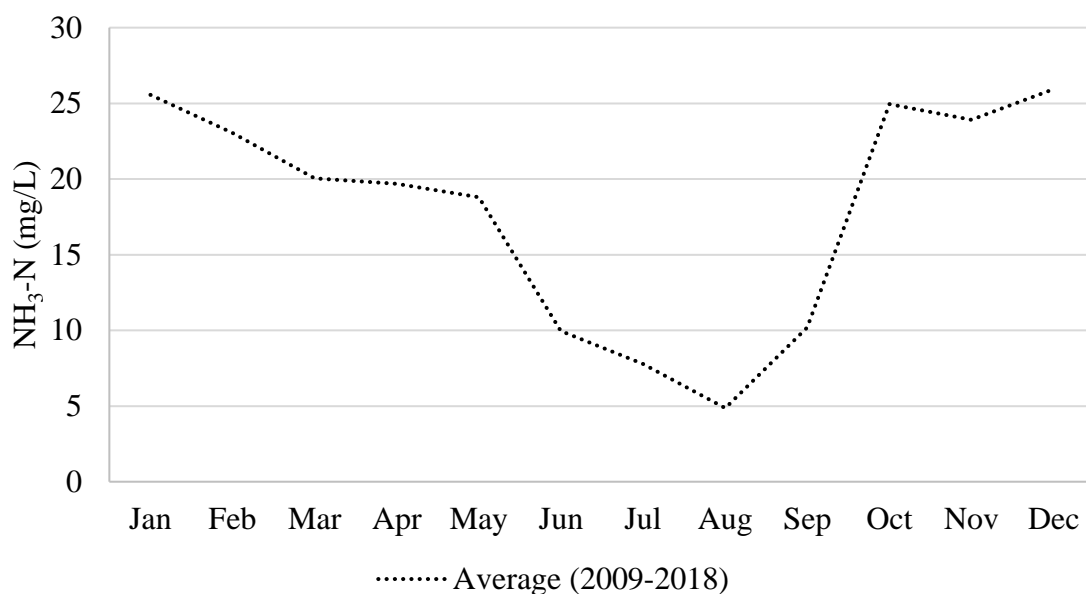


Figure 8. Average monthly ammonia concentrations for OP1 effluent between 2009 and 2018.

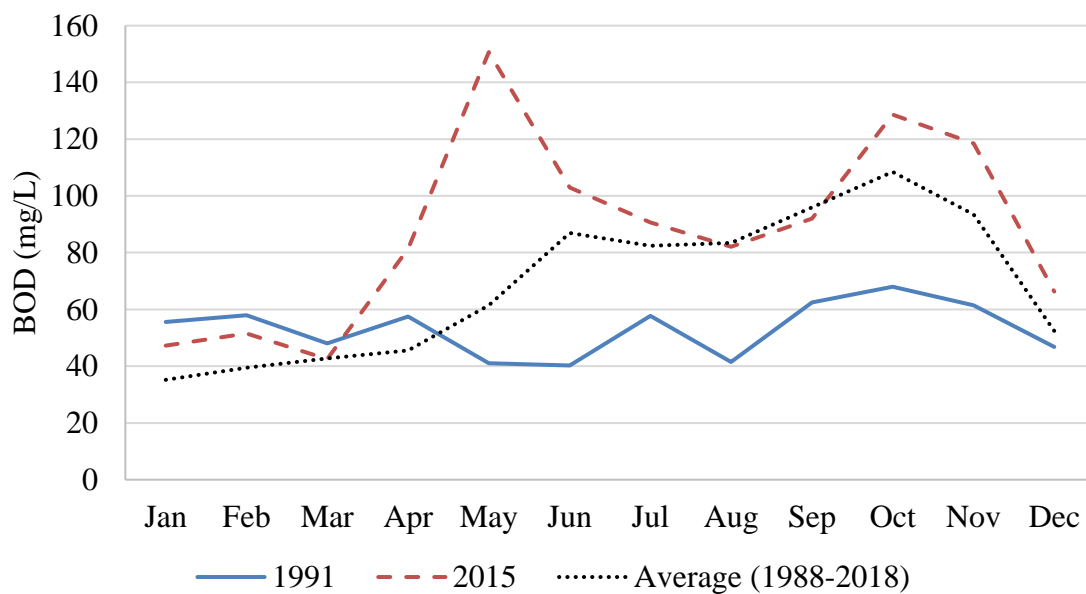


Figure 9. Average monthly BOD concentrations for OP1 effluent between 1988 and 2018. Includes a high concentration year (2015) and low year (1991).

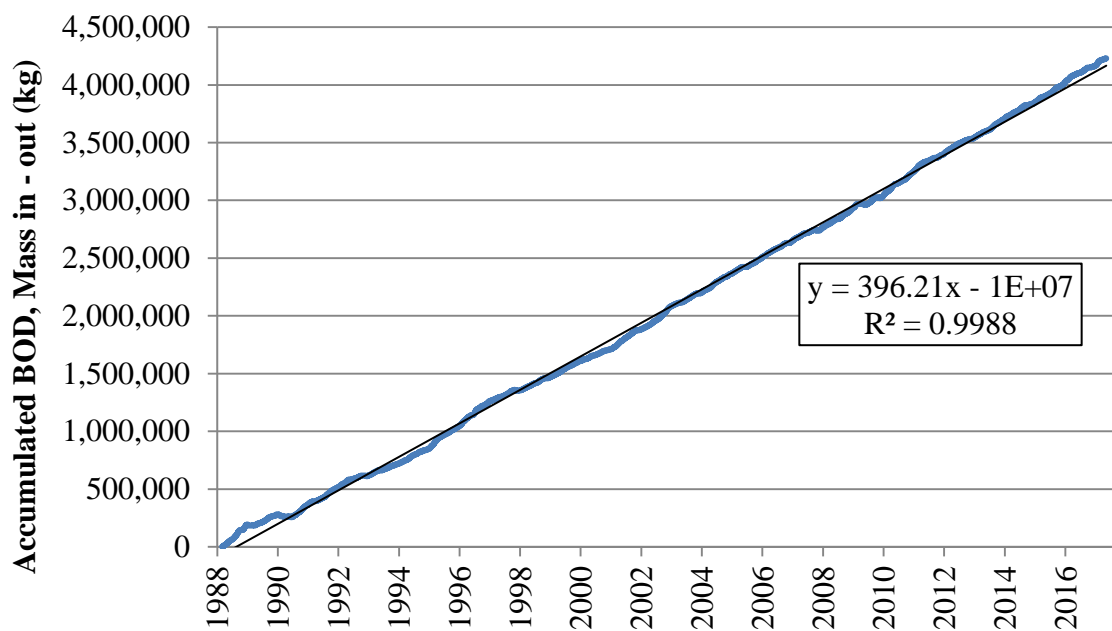


Figure 10. Accumulated BOD in OP1 from 1988 to 2017.



Figure 11. Accumulated TSS in OP1 from 1988 to 2017.

Since 1996, there have been three solids studies on OP1. The first study was a master's thesis completed by Logan Olds (1996) and was done to estimate the volume of solids that had been stored in the pond up to that point. The second study was done in 2008 by AMRI to replicate and confirm the results of Olds' thesis.

The 1996 study measured 80 sample points across OP1 using a Phleger corer. The Phleger device is normally used for geological or limnological studies involving coarser sediments. The device relies on its own mass to push through the solids layer. The volume of solids was measured indirectly, using measured mass values and estimated density values. The results of the study revealed the majority of the solids in OP1 are along the diked boundaries of the pond, with the greatest volume of solids being at the northeastern corner (Figure 12). It was suggested that the primary force of solids distribution in OP1 is wind currents. The study also concluded that OP1 had reached an equilibrium mass of solids and that treatment of the solids was required due the internal load of the accumulated mass. Unfortunately, the original data of this study is unavailable so the information in the report cannot be reanalyzed. Original data would be required to transform the mass/volume concentration data used in the report to a more comparable mass/mass concentration of solids. A series of aerators were installed in the midsection of OP1 after this study. The aerators were primarily used for odor control and currently only two of the original eight units are operational.

The 2008 AMRI study measured 70 samples points using a custom sampling device (Figure 4). The custom sampler was developed to not compact the wet OPBS and allow for a more accurate measurement of the OPBS depth. The results of this study

reached the same conclusion as Olds' regarding solids distribution in the pond, but the northeast corner was not the highest volume area (Figure 13). However, the 2008 study added a new element in estimating the total occupied volume of OP1 at approximately 20%, with an average pond depth of 5.7 ft and solids depth of 1.1 ft. This additional metric gives a better sense of the relative volume of OP1 occupied by solids. The original data from this study is available for further analysis.

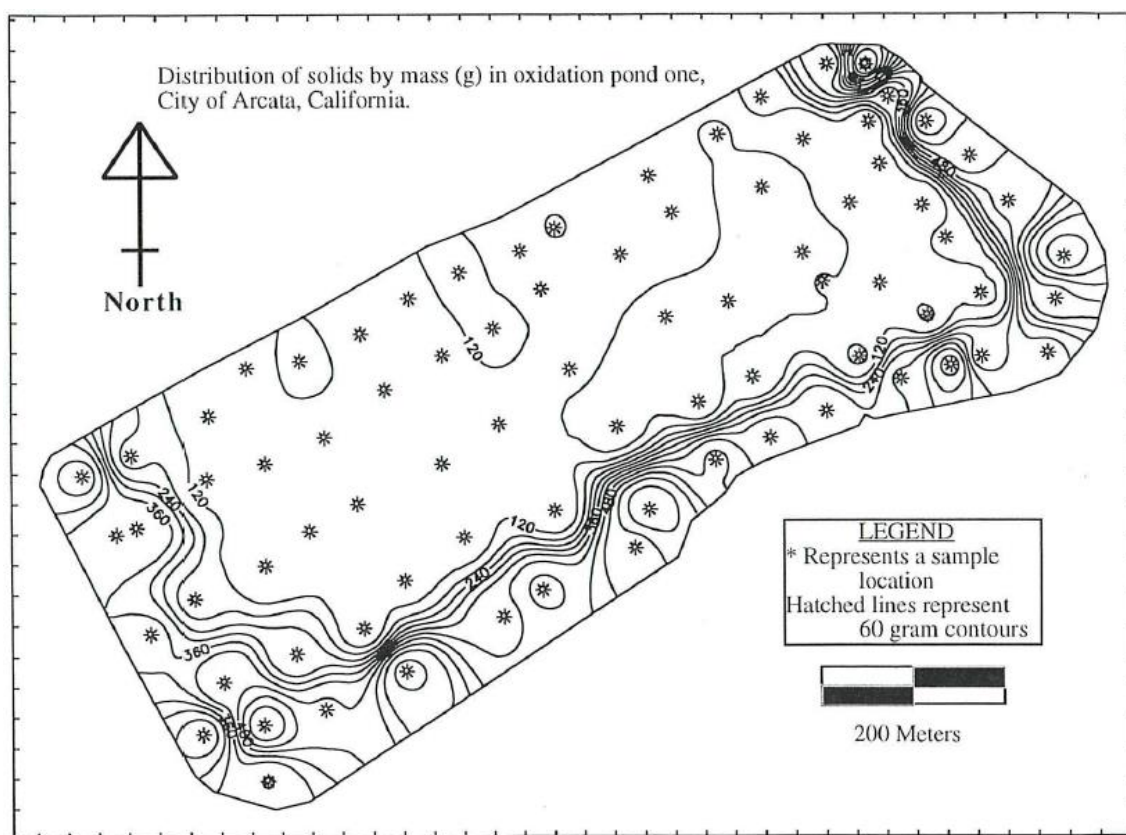


Figure 12. OPBS distribution by volume in OP1 (Olds 1996).



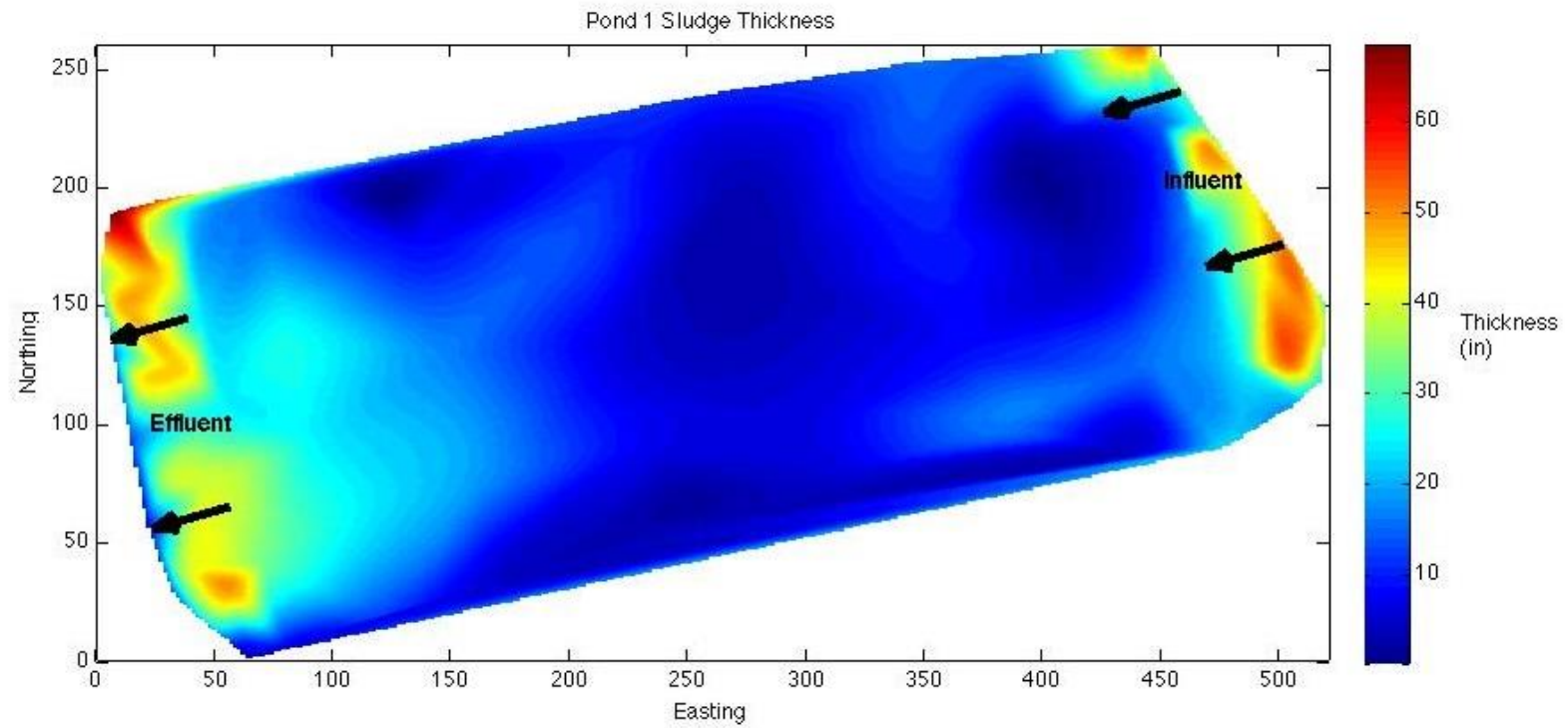


Figure 13. Original map of OPBS distribution by volume of OP1 (AMRI 2008).

The third study conducted on the AWTF OPs was a 2014 survey of metal concentrations (Hurst et al. 2014). Six sample points within OP1 were selected for metal analysis using an inductively coupled plasma mass spectrometer. Metal concentrations were measured over the course of a year (2012-2013) to determine temporal variation and to estimate accumulation rates. The results of the study found that metals of concern (cadmium, copper, lead, nickel, and zinc) were well below regulatory limits for biosolid composting. The accumulation rate of metals also determined that another 45 years of influent would be needed to reach the maximum concentration limit for composting.

## METHODOLOGY

The methods for this project were developed to characterize the OPBS at the AWTF. The methods are split into the three characterization types: spatial, biogeochemical, and treatment. Both the biogeochemical and treatment characterization methodology required information from the spatial characterization, so the spatial methods were developed and executed first. Most of the spatial data was collected between May 2018 and July 2018, and a small subset of samples were collected in January 2019. Data for the biogeochemical characterization was collected in December 2018. Data for the treatment characterization was collected between September 2018 and March 2019. All data collection for this project was done by AMRI researchers except for total Kjeldahl nitrogen (TKN) tests that were sent to a professional analytical laboratory. Instrumentation for collection and analysis was either provided or fabricated by AMRI or provided by the Environmental Resources Engineering department water quality lab.

### Spatial Characterization of Biosolids

After reviewing sampling methods from literature, a manual OPBS measurement method was selected to collect the bathymetric data. A 9-ft, clear PVC pipe with gage tape fixed to the body and a swing gate at the driving end of the pipe was fabricated by a previous AMRI researcher and Environmental Resources Engineering graduate student (Figure 14) (Sipes 2017). The solids measurement device (SMD) was designed to drive

through the water and solids depth, and upon reaching the bottom of the pond, swing the bottom gate closed to capture the biosolids in the column. The total depth of the location was first recorded then the SMD was retrieved with the collected biosolids column. Once on the boat, the captured solids column was allowed to settle for approximately one minute to reduce the potential error from resuspension. After settling, the solids depth was recorded along with field notes of observations regarding apparent viscosity, particle size, and color.

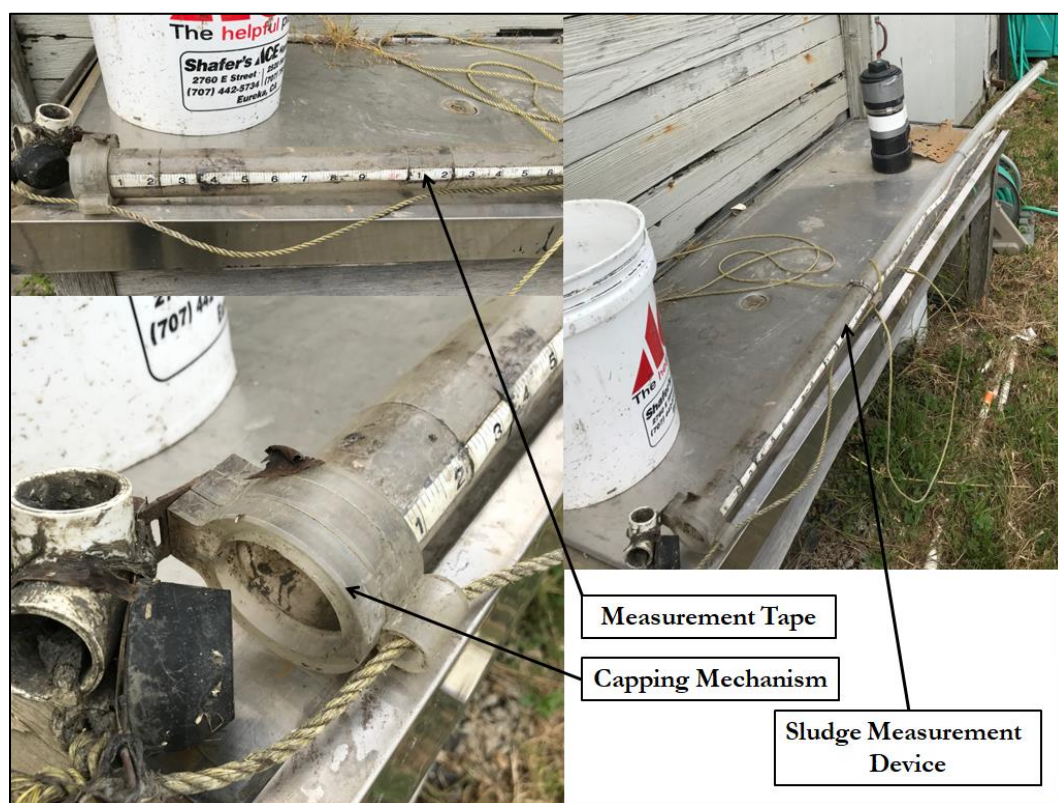


Figure 14. Solids measuring device developed by AMRI (Sipes 2017).

A total of 253 samples were collected across the 24-acre pond with each location's coordinates being recorded using a Garmin eTrex® 10 GPS unit (Figure 15). A

mixed-resolution sampling regime was developed as data was collected. A lower spatial resolution of sampling was used in areas of OP1 that have low variability in solids accumulation and a higher spatial resolution of sampling was used in areas with greater variability and solids volume. This adaptive resolution was implemented to reduce sampling time. High resolution sampling was used to determine where the boundaries of OPBS existed within OP1.

There are several sources of potential error in this method. The first potential source of error is the time dependence of water elevation in the ponds. The water surface elevation of OP1 varies depending on the influent flowrate to the AWTF and volume gained by precipitation. To mitigate this, sampling was done over the dry, summer months where there is little variation in both AWTF influent flows and insignificant precipitation.

Second, due to the thickness and compaction of biosolids in deep areas, the sampling device would not always capture the entire solids column. If unaccounted for this would create a low-volume bias of the survey. To mitigate this error, special attention was directed to the clear sampling device. When this failure to capture the entire column would occur, there would be a significant difference in the measured total water depth and the “captured” total water depth, due to the thick solids not completely sealing the bottom of the sampling device. The difference in “true” and “captured” total depths was added to the solid depth measure as it represents the point where solids were no longer entering the SMD.



Figure 15. The 253 sampling locations for the OP1 spatial distribution characterization, with the highest density at the influent (east) and effluent (west) ends.

Collected spatial data was then transcribed to an Excel spreadsheet for data manipulation and back-up storage. The total pond depth, water depth, and OPBS depth measurements were sorted and organized for analysis. These depths were converted from

feet to meters for use with a projected coordinate system (PCS). The organized spatial data was imported to ArcMap version 10.6 as shapefiles for analysis. Spatial data was projected to use the Universal Transverse Mercator, Zone 10 North PCS. Before interpolating the projected data, it was tested for correlation using the ArcMap intrinsic Global Moran's I autocorrelation test, which provides a calculated z-value. If the z-value is greater than 2.5 then the data is correlated, and all three depth profiles could then be interpolated to rasters using the IDW method. The IDW method was selected for use due to its simplicity. Excess interpolation area was removed using the intrinsic Clip tool. The interpolated and processed data was then used to create three result maps: total depth, OPBS depth, and a ratio of OPBS to total depth. The ratio map was created to better represent the level of accumulation for each area of OP1. Finally, volume estimates for the OPBS were calculated using the intrinsic Cut and Fill process from the total depth and water depth interpolated rasters. The water volume estimates were made using the same process but instead used the total depth and solids depth rasters. This same process was applied to the raw spatial data from the 2008 AMRI survey to allow for a direct comparison of volume estimates. A flow chart for the ArcMap methodology is shown in Appendix A (Figure A-1).

To determine the impact of resolution and evaluate the required sampling effort, a sensitivity analysis was performed. The resolution of the sample grid was reduced by 50% and 67% in two recalculations of the volume. Sample points were removed in order of their collection, so, for the 50% resolution analysis, every other collected sample was removed. This strategy preserves the effect of increased sample intensity in variable

zones while still theoretically reducing the sample time. The calculated volume estimates from the two reduced resolution runs were then compared to the full resolution result.

### Biogeochemical Characterization of Biosolids

Determining the biogeochemical properties of biosolids allows for a better assessment of treatment options. Based on the information obtained in the literature review and using the knowledge of what parameters are of most importance to the AWTF along with the available instrumentation, the following table summarizes the monitored parameters for this characterization phase of the project (Table 1).

Table 1. Measured parameters and their associated standard methods.

Parameter	Analytical Method of Analysis
Ammonia-N	Standard Method 4500-NH <sub>3</sub> D <sup>1</sup>
Nitrate-N	Standard Method 4500-NO <sub>3</sub> <sup>-</sup> D <sup>1</sup>
Organic Nitrogen-N (TKN)	Standard Method 4500-N <sub>org</sub> B <sup>1</sup>
COD	HACH Method 10067 <sup>2</sup>
Total Solids	Standard Method 2540 B <sup>1</sup>
Volatile Solids	Standard Method 2540 E <sup>1</sup>
BOD	Standard Method 5210 B <sup>1</sup>
CBOD	Standard Method 5210 B <sup>1</sup>

<sup>1</sup>(APHA 2017)

<sup>2</sup>(HACH n.d.)

The moisture content and density of the OPBS were also of great importance to this characterization phase. With these two values for each location, the mass concentration of each parameter could be given as a function of OPBS mass (mg



Parameter/ kg OPBS). This unit of concentration allows for a direct comparison between locations and depths because it accounts for the amount of OPBS at each sample point. The moisture content was calculated using mass measurements from the solids slurry pre- and post-evaporation. This data is collected during the same time as the total solids results. The density for each sample was estimated using mass and volume measurements.

OPBS used for this characterization process were homogenized using a blender before being introduced to each testing environment. There was a concern that OPBS would create a biased effect on the ammonia and nitrate probes results by blocking the membrane and preventing the bulk volume from being measured. To test this, a serial dilution of the OPBS was done. If the OPBS negatively affected probe performance than a non-linear response in the nutrient concentrations would be detected. The homogenization of the sample was also necessary for COD measurements. Large solids would create a bias effect for concentration values as well as cause clogging issues with pipettes.

The biogeochemical composition of the OPBS may be different depending on location and depth. For example, the solids near the effluent are hypothesized to have a greater mass fraction of algal solids than sediment, and these concentrations may increase as depth and compaction increases. To account for this, each of the parameters listed in Table 1 was measured at five locations within OP1 (Figure 16), and each location, except for sample point 3 (mid-pond), had subsamples at three different depths. The solids depth at point 3 was not great enough for a core sample beyond 1 foot. The five sampling

locations were selected based on the results of the spatial characterization. The five locations included areas with high volumes, low volumes, and different perceived biosolids viscosities (the “stickiness” of the solids with the sampler). Sampling locations were limited to have a total depth of less than 8 feet to allow for core sampling. Depth samples were collected using a custom core sampler that was created to mimic the tool used in Nelson et al. (2004) (Figure 17). Like the previous sampler, the corer was constructed out of clear PVC pipe. Sample ports were installed at 3-inch intervals with large enough diameters to allow biosolids to flow freely from each port (5/8-inch). To collect the core sample, the corer was driven to the bottom of OP1 and with the natural clay liner acting as a seal. Once sealed, the top of the corer was capped to remove atmospheric pressure, the device was extracted, the supernatant (OP water) was removed via the ports, and then the biosolids could be extracted from the lower ports.

To make comparable measurements, three depth layers were defined and sampled at all locations. The first layer for each sample (top) was defined to be the first foot of OPBS. This layer represents the youngest solids at each location and were expected to be the least compacted. The third layer (bottom) was defined to be the bottom foot of OPBS. This layer represents the oldest and most compacted solids. The second layer (middle) is the most variable and it is defined as the intermediate OPBS. The sample for this layer is collected using the ports between the first and last of foot of OPBS. The purpose of the middle sample is to serve as a distinct separation between the top and bottom samples while also revealing whether the bulk of the column is more like the top or bottom.

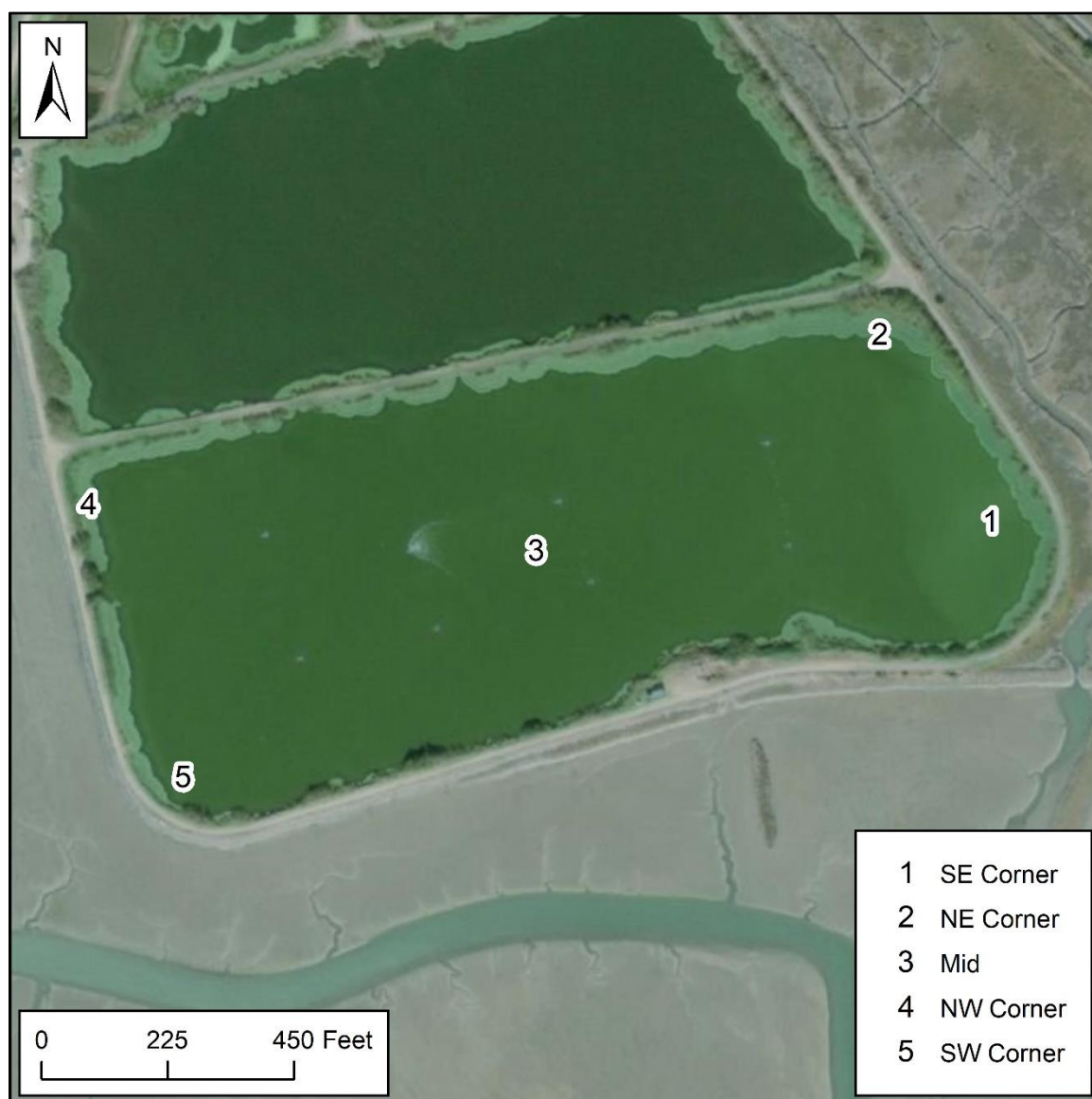


Figure 16. Locations for biogeochemical characterization sampling.

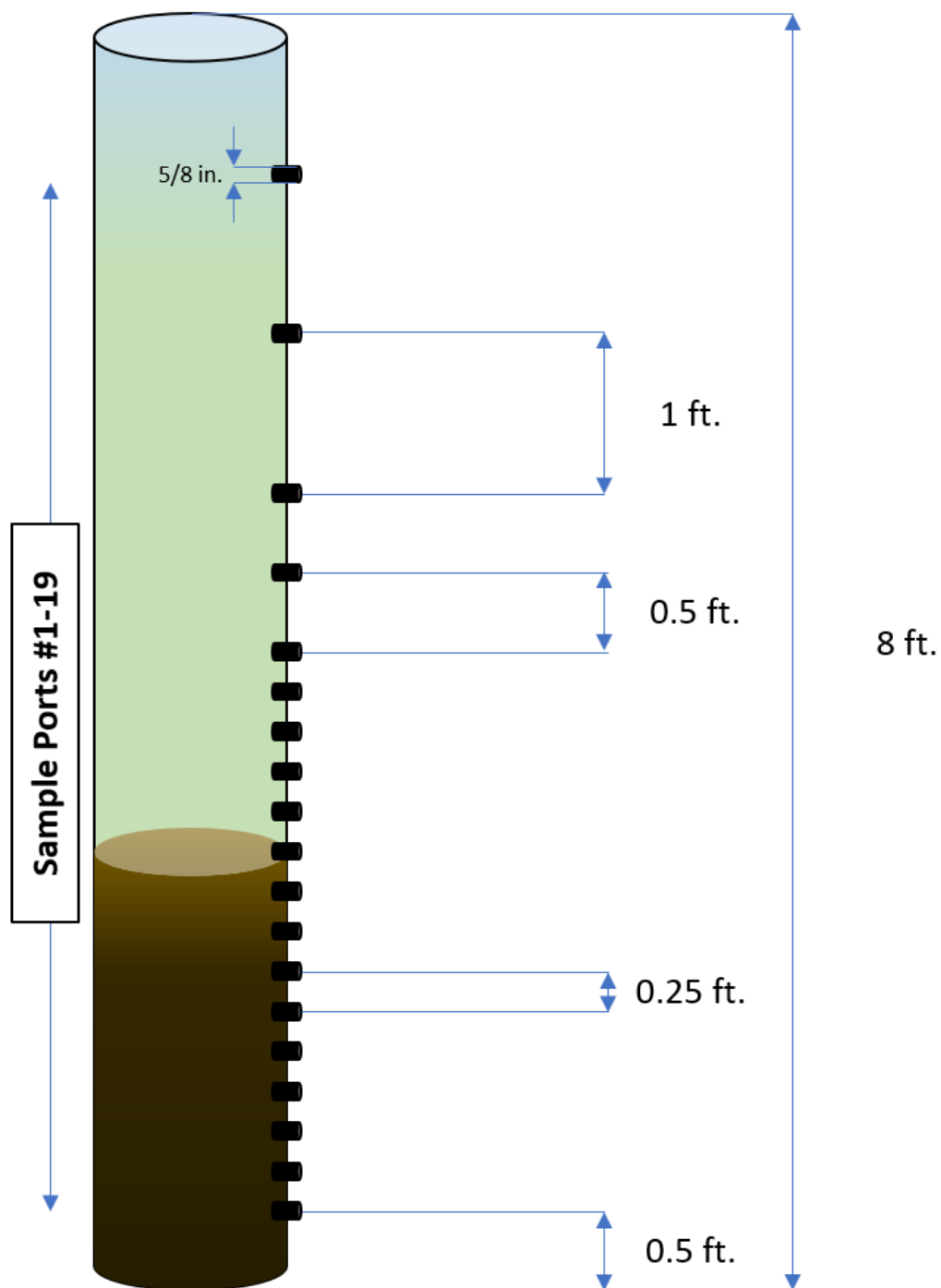


Figure 17. Coring device used to collect biosolid samples at varying depths.

## Treatment Options for Biosolids

The objective of this phase was to evaluate the performance of an OPBS treatment option. This required monitoring key water quality parameters (determined from the previous phase) as pilot-scale treatment is tested. The pilot-scale depth-aeration testing utilized two cylindrical reactors (2.3 and 2.4 ft diameters) that allowed a similar ratio of sludge/water depths as observed in the pond to be continuously aerated and monitored (Figure 18). For each pilot-test, OPBS were extracted using a pump capable of moving a solid slurry. The pumping process introduces more supernatant water than using the core sampler, however the required volume of solids made pumping a necessity for the project. OPBS were added to the reactor to account for approximately 40% of the total volume; this ratio roughly represents the ratio of solids at sampled locations. The remaining 60% was filled using surface water from OP1. OPBS used for these trials originate from sample points 1 and 4 from Figure 16 and are referred to as influent and effluent solids, respectively. The measured parameters and methods for this component of the project are similar to Table 1 but excludes TKN and includes soluble BOD (SBOD).



Figure 18. Reactors used for aeration trials. The left reactor has a diameter of 2.3 ft while the right reactor has a diameter of 2.4 ft.

A total of six treatment trials were conducted for this project with the shortest trial operating for just over two weeks and the longest being just over six weeks (Table 2). Each trial had an air flow rate of 0.3 cfm that was controlled using an electrical blower and rotameter. The air was introduced through a fine-bubble diffuser at the bottom of the reactor. The 0.3 cfm air flowrate was selected due to its ability to keep the OPBS suspended and well-mixed while providing adequate DO for biological processes. DO was monitored throughout each trial and never dropped below 70% saturation.

Each trial reactor was shielded from environmental conditions such as sunlight, precipitation, and animal interaction using covering tarps and tie-downs. The treatment reactors were monitored for water loss through evaporation/misting and concentrations for parameters of concern were corrected accordingly. Temperatures of the reactor volume were monitored but not controlled. Water temperatures ranged from 16-20 °C for the first two trials and 7-13 °C for the last four trials.

The first two trials were conducted without monitoring or maintaining alkalinity concentrations while the last four trials were switched to be alkalinity controlled through calcium carbonate addition. Each calcium carbonate addition was recorded by the mass added, but no impacts besides pH control were expected. pH monitoring was done for each trial and the results from the first two experiments identified the need for the alkalinity control.

Table 2. Operating details for each depth-aeration treatment trial.

<b>Trial</b>	<b>Trial Period</b>	<b>Origin of Solids</b>	<b>Volume of Solids (ft<sup>3</sup>)</b>	<b>Controlled Alkalinity?</b>	<b>Indoors or Outdoors ?</b>	<b>Average Temp. (°C)</b>
1	09/23/2018 - 10/12/2018	Influent	4.0	No	Outdoors	17.5
2	10/13/2018 - 11/30/2018	Influent	7.4	No	Outdoors	14.7
3	01/10/2019 - 02/01/2019	Effluent	5.9	Yes	Indoors	11.5
4	01/10/2019 - 02/01/2019	Effluent	5.5	Yes	Indoors	11.1
5	03/01/2019 - 04/17/2019	Influent	5.9	Yes	Indoors	10.4
6	03/01/2019 - 04/17/2019	Influent	5.5	Yes	Indoors	10.1

Additional experiments were performed to track nitrogen transformations during aeration. To mimic the pilot-scale reactors, five 5-gallon buckets were filled with an identical 40% OPBS slurry and aerated using simple aquarium aerators and air stones. Ammonia and nitrate were the only parameters measured in these bucket tests. Four samples times were used based on the nitrogen transformation pattern of the pilot-scale reactors. Along with these tests, an additional bucket test was used to measure the nitrite concentrations of the OPBS slurry as aeration progressed. Daily samples were collected starting at the beginning of aeration and stored at 4 °C until being shipped to an analytical laboratory (Alpha Analytical) 14 days later.



## RESULTS AND DISCUSSION

All presented concentrations are on a mass/mass dry weight basis (mg/kg) unless otherwise noted.

### Spatial Characterization Outcomes

The results of the solids survey are presented in three different maps. The total depth map (Figure 19) shows that the greatest depths in the pond occur at the outlet (western) border of OP1 (~12 ft), and that the middle of OP1 is a uniform 5.5 ft depth. The OPBS map (Figure 20) shows that both the inlet (eastern) and outlet (western) borders are the primary locations of accumulated OPBS. The outlet border of OP1 has OPBS depths as great as 9 ft. The final map shows the ratio between OPBS depth and total depth for OP1 (Figure 21). This map shows that both the inlet and outlet borders of OP1 have the highest fraction of OPBS to total depth. The inlet section of OP1 has areas that are over 95% OPBS while the middle of OP1 can be as low as 10% OPBS depth.

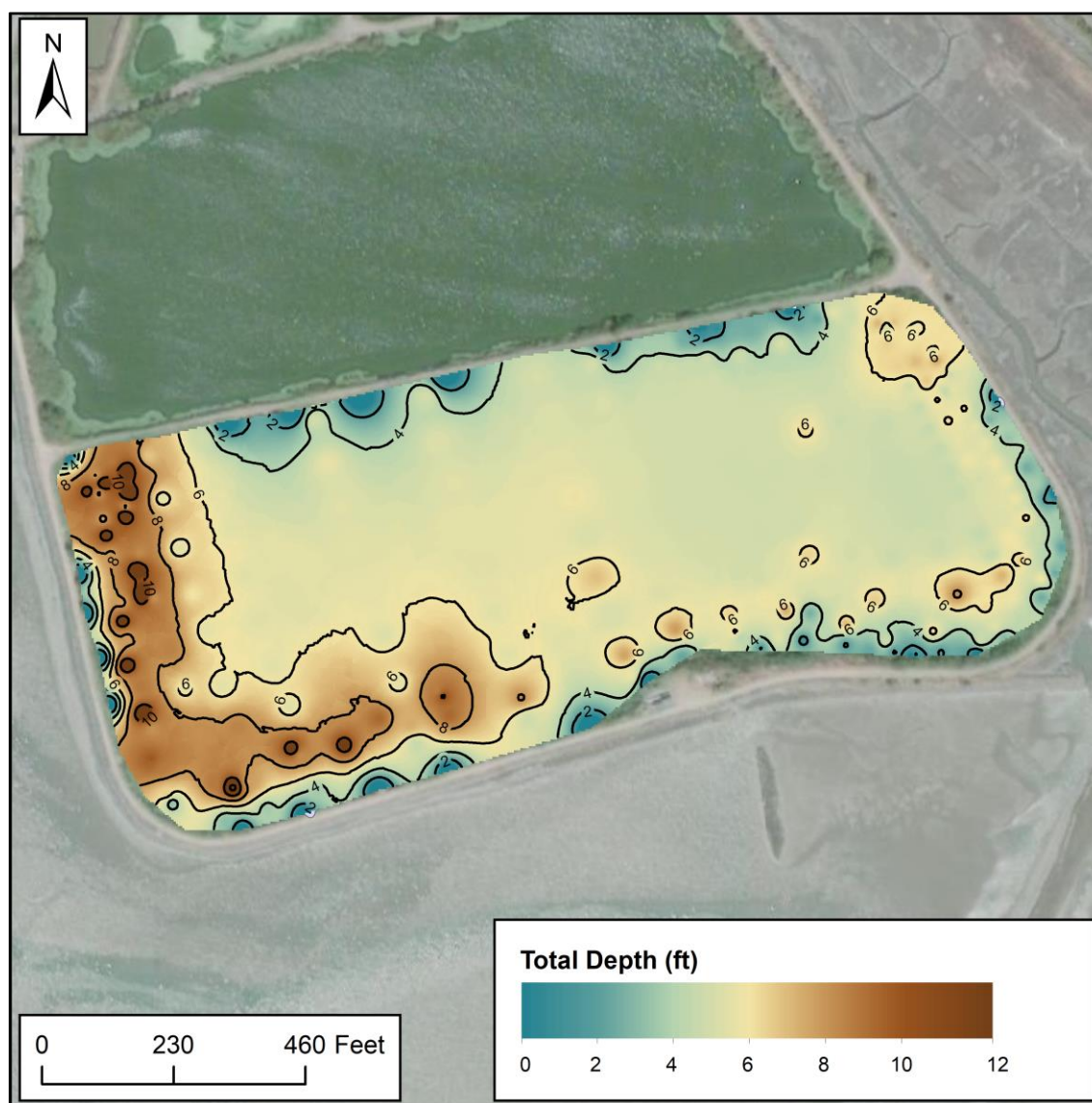


Figure 19. Spatial distribution of total depth in OP1 with 2-ft contours. Flow moves from east to west.

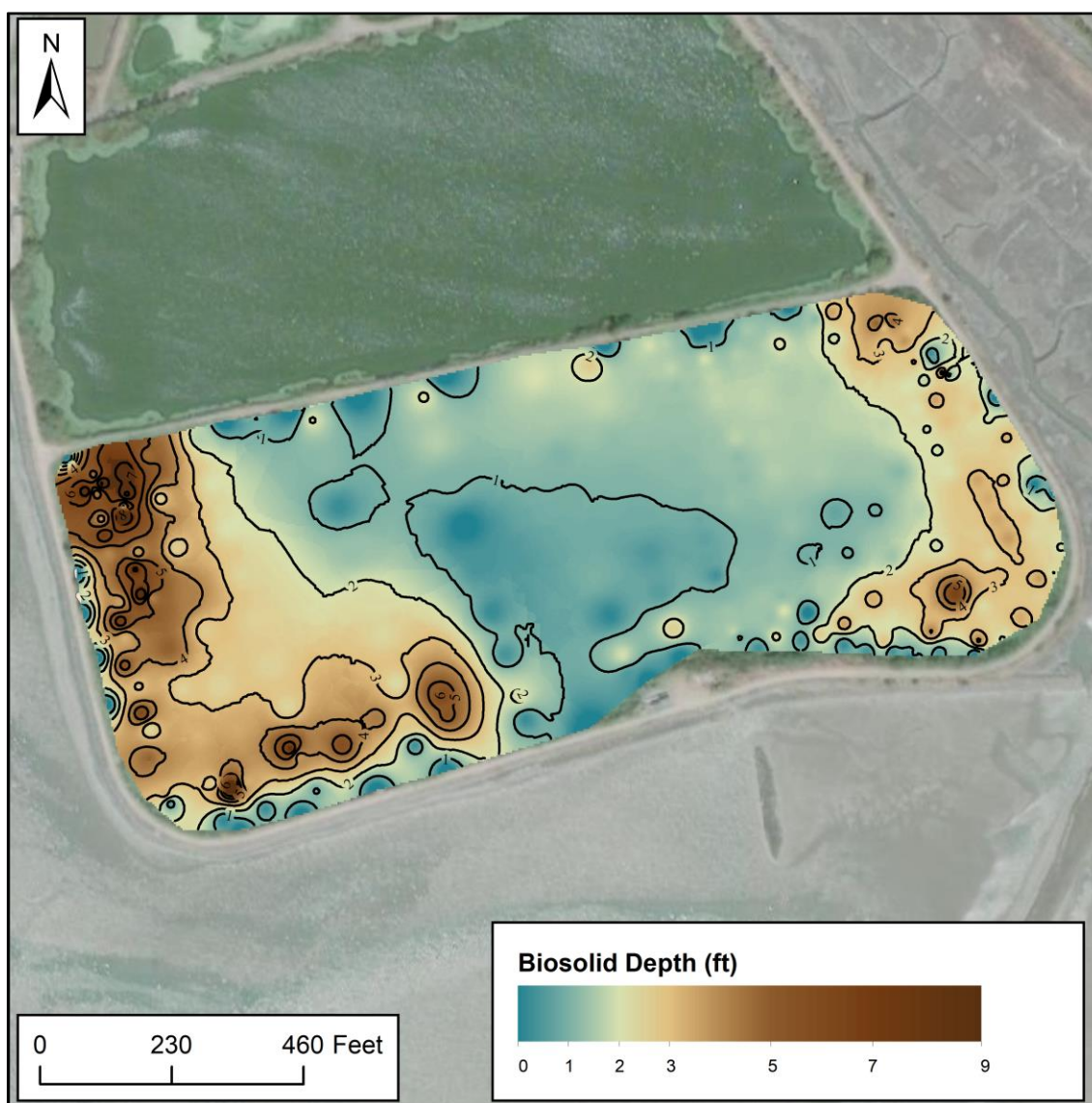


Figure 20. Spatial distribution of biosolid depth in OP1 with 1-ft contours. Flow moves from east to west.

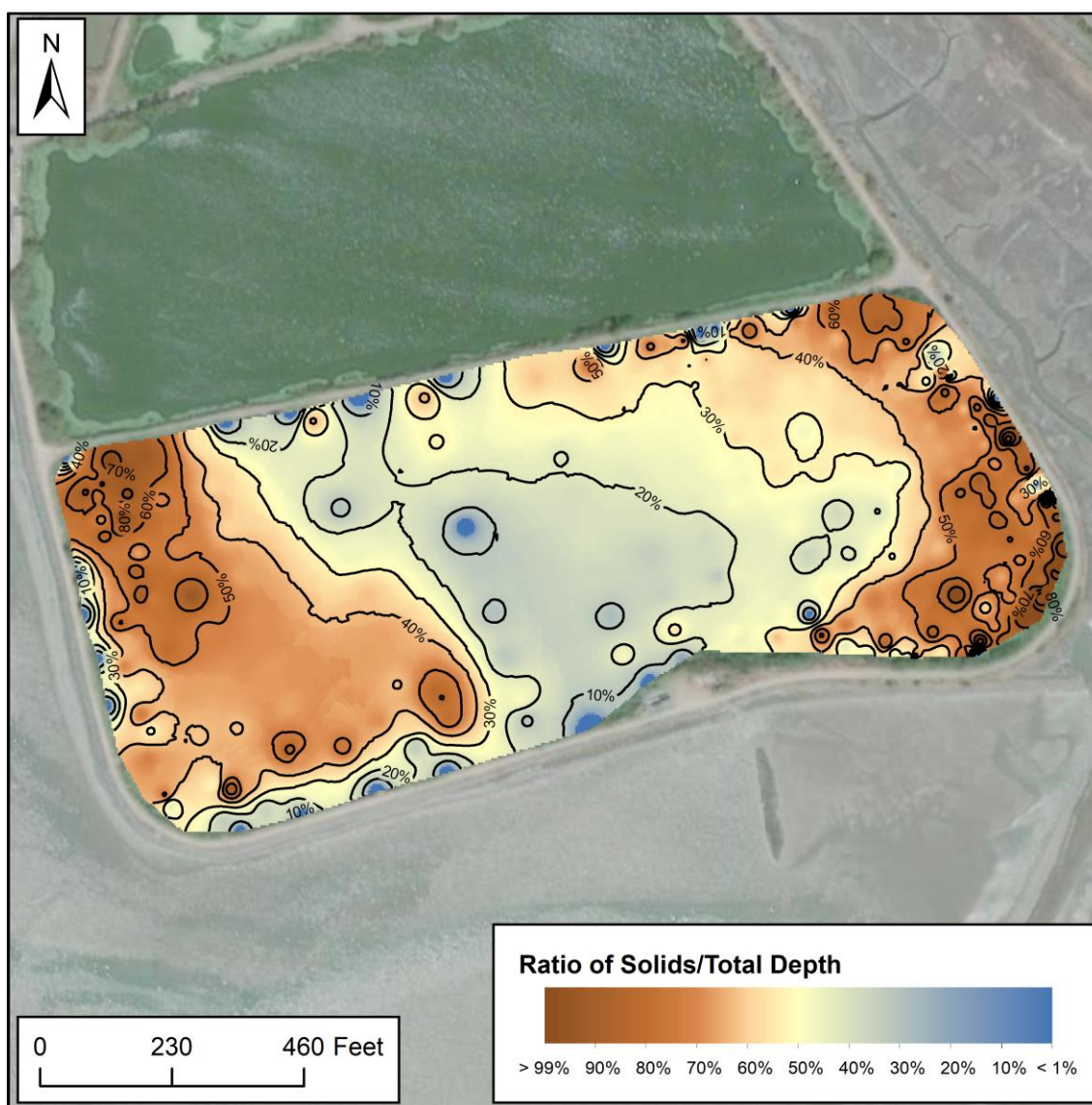


Figure 21. Spatial distribution of solids to total depth ratio in OP1 with 10%-contours.

Flow moves from east to west.



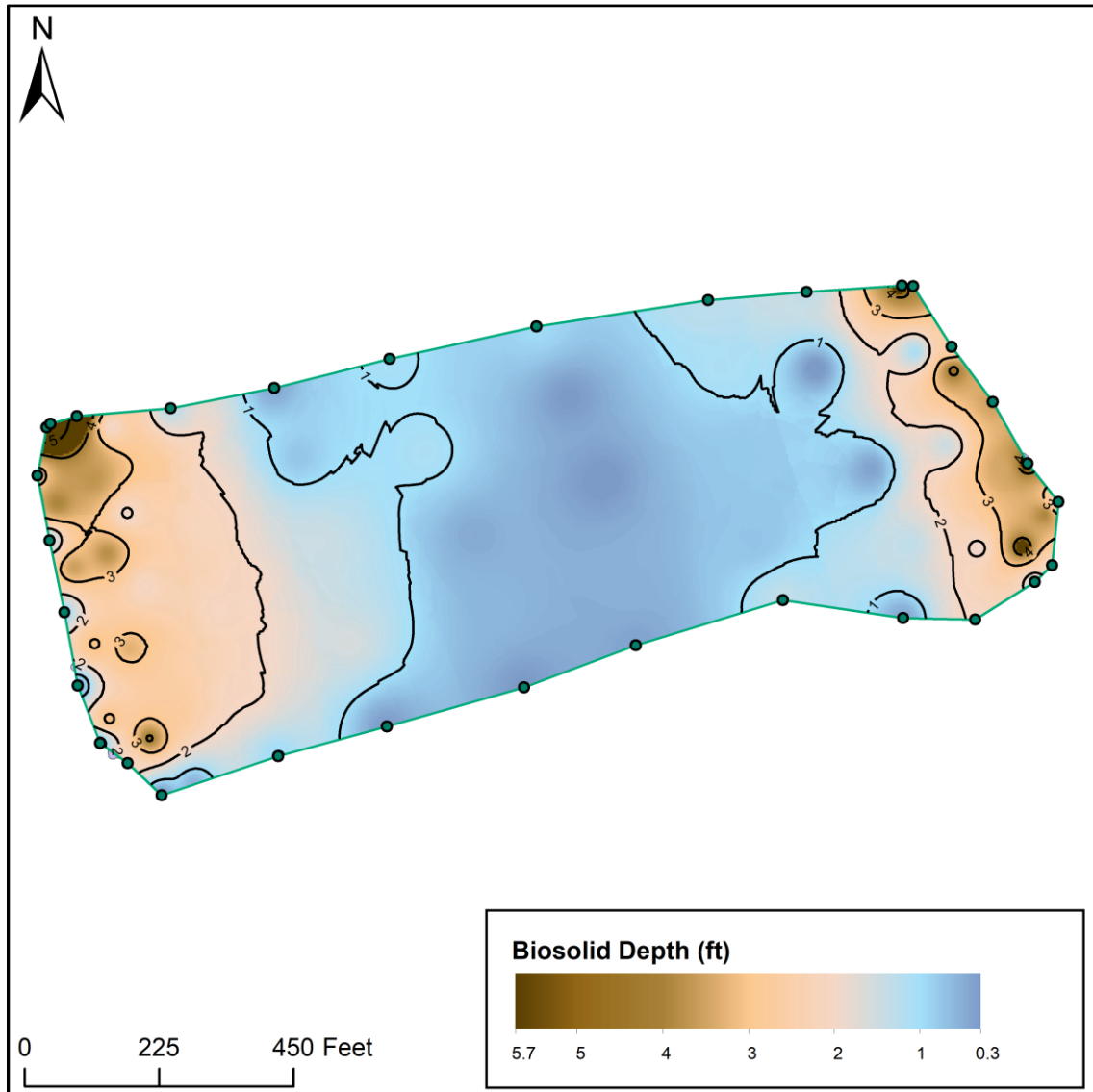


Figure 22. Spatial distribution of biosolid depth in OP1 using data from the 2008 AMRI survey (with 1-ft contours). Flow moves from east to west.

The primary result of the spatial characterization is that approximately 62,000 m<sup>3</sup> of solids (representing 38% of the total volume of OP1) is occupied by wet OPBS (Table 3). This represents an estimated 6% increase from the 2008 survey. The majority of these solids are located at the influent and effluent zones of the pond with the mid-section

yielding a relatively low average solids depth of approximately 1 ft (Figure 20). This lack of accumulation in the midsection of OP1 is an indication that the aerators that were implemented for odor control may have affected the distribution of OPBS. While no direct relationship can be made between the aerators and the lack of accumulation found in this study, it is something to consider for future studies or facility upgrades. Other possible explanations for the low volume in the center of OP1 are that the increased DO from the aerators allowed for a greater amount of digestion or that the wind forces are greatest at the center of OP1 away from the protecting borders and the solids were transported to the hydraulic dead-zones.

Ultimately, any stored OPBS in the pond has an effect on the hydraulics of the system. Though the OPBS are not tightly compacted at every location, they still limit the movement of water throughout the pond and retard any flow moving through the solids themselves. Instead of being able use the OP for storage in high flow scenarios, there is an uncertainty of what volume of the pond is active. The greater fraction of the pond that is inactive, the less effective volume there is which increases the impact of influent storm flows. This reduces the operational flexibility that OPs offer involving storage capabilities.

Table 3. OPBS accumulation represented as wet volume in Oxidation Pond 1 for the 2018 and 2008 surveys.

<b>Parameter</b>	<b>2018 Survey</b>		<b>2008 Survey</b>	
	<b>m<sup>3</sup></b>	<b>yd<sup>3</sup></b>	<b>m<sup>3</sup></b>	<b>yd<sup>3</sup></b>
Solids Volume	62,115	81,243	37,077	48,495
Water Volume	103,130	134,889	78,509	102,686
Total Volume	165,245	216,132	115,586	151,181
%Solids Volume	38%		32%	

The increased accumulation of OPBS at the eastern, inlet border (>90% wet OPBS by volume) is an expected result based on previous literature studies and an understanding that solids at the influent of OP1 have a greater residual grit content as a result of receiving influent from primary treatment. However, of greater interest, is the western, outlet border of OP1. The total pond depths in this zone were much greater (10-12 ft) than the average depth of the rest of the pond (5.5 ft). This observation is what led to the revelation of the borrow pits that were created during the construction of the pond system. This deep zone has accumulated a large of amount solids over its fifty years of operation. The effects of fill-in were most likely greater during the last 30 years of operation with the effluent control box creating low-velocity and stagnant areas along the western border. Prior to this (when water flowed north to south in OP1), the western border was an edge and may have accumulated solids at a similar rate as the present day northern and southern borders. While the existence of the borrow pits was previously

known (Figure 7), its impact on solids accumulation was not previously documented and its effects on OPBS storage was unknown.

Both previous surveys completed by Olds (1996) and AMRI (2008) did not indicate any notable differences in solids or total depth from the borrow pits and the inlet border. This may be attributed to the sampling techniques that were used in those studies and reveals the sensitivity of sampling location and method when determining OPBS accumulation. While the sampling of this study was extensive, it is still possible that important data may have been missed. Experimental errors may partially explain why the 2008 estimate of 37,000 m<sup>3</sup> of solids (AMRI 2008) can be nearly doubled (to 67,000 m<sup>3</sup>) in the span of ten years (Table 3). An encouraging check of the collected data, however, also lies in these previous studies. Noticeable similarities in the distribution of solids from both the 1996 and 2008 surveys and this projects results indicate that locations of accumulation are correct.

Assuming that the 2008 survey did not capture the depth of the borrow pits but did provide an accurate solids volume percentage, an estimate of an “adjusted” solids volume can be made (52,878 m<sup>3</sup>). By applying an average moisture content (92%) and density (1.02 kg/L) (from the biogeochemical characterization results), the volume difference between the 2008 and 2018 surveys can be transformed to a mass unit. Using this information and historical TSS data (Figure 11), a comparison of accumulated mass can be made (Table 4).



Table 4. Estimated mass loads accumulated between 2008 and 2018 using historic AWTF and survey data.

<b>Parameter</b>	<b>Year 2008</b>	<b>Year 2018</b>	<b>Difference (lbs)</b>
Est. Mass Accumulation from Influent TSS Loading Analysis (lbs)	900,000	1,279,000	379,000
Est. Volume from Surveys (yd <sup>3</sup> )	69,000	81,000	-
Est. Mass Accumulation from Spatial Analysis (lbs)	9,700,000	11,416,000	1,716,000

While this analysis ignores the solids produced or digested internally in OP1 (it only accounts for influent and effluent and does not consider internal gains or losses), it does show that the mass estimates of accumulated solids between the two methods are on the same order of magnitude (less than 1-log difference). This mass estimate can then be used to relate the stored solids in OP1 to the annual solids load that the AWTF receives (assuming the raw influent would bypass the clarifier and go directly to OP1). Using an average annual solids load of approximately 1,376,000 lbs per year, the amount of OPBS stored in the pond is equivalent to 8.3 years of AWTF influent load (Table 5). Also, assuming a service population of 18,000 people and a project lifetime of 30 years, the OPBS stored in OP1 is roughly equivalent to 5,000 new/potential users.

Table 5. Estimates of OPBS mass in OP1 relating to time and population.

<b>Parameter</b>	<b>Value</b>
Estimated Solids Stored in OP1 (lbs)	11,415,718
Average Annual AWTF Influent TSS 1988-2018 (lbs/year)	1,375,964
Years-Worth of Stored Solids (year)	8.3
Average Annual TSS Load per Person (lbs/year/person)	76
30-Year Estimate of per Person Load (lbs/person)	2,293
Allowable Increase in Population (people)	4,978

Artificially reducing the resolution by removing sample points reduces the estimated volume of OPBS. By removing one-third and one-half of the sample points, the estimate of the volume of OPBS is reduced by approximately 7% and 10% respectively (Table 6).

Table 6. Estimated OPBS volume using reduced sampling resolution.

<b>Parameter</b>	<b>2/3 Resolution</b>		<b>1/2 Resolution</b>	
	<b>yd<sup>3</sup></b>	<b>%Reduction from Base Value</b>	<b>yd<sup>3</sup></b>	<b>%Reduction from Base Value</b>
Solids Volume	75,711	6.8%	72,989	10.2%
Water Volume	126,778	6.0%	123,659	8.3%
Total Volume	202,489	6.3%	196,648	9.0%
%Solids Volume	37%	0.5%	37%	1.3%

The sensitivity of sample resolution was performed to better understand the impact of the number of sample points and the magnitude of the estimated OPBS volume. The results of this analysis indicate that even with a 50% reduction in sample points there is only a 10% difference in the estimated OPBS volume. This result supports two conclusions. First, the difference in the volume estimates from this study and the 2008 survey are the result of something greater than the sampling resolution, which (along with the historical knowledge of the borrow pits) adds credibility to the sampling methods proposed in this project. There are still sources of experimental error resulting from the GPS method used like satellite drift and signal receiver limitations. Second, the time spent sampling pond depths can be effectively halved depending on the amount of available resources for a fraction of the effect on volume estimates. For a sampling regime that required approximately 300 people-hours, the advantages of the option to half the time can be significant depending on system size.

Finally, field observations were made regarding the differences in physical characteristics between solids from the influent and effluent zones. The influent zone solids were generally darker and stickier while the effluent zone solids appeared to be lighter in color and more loosely packed. These results were an early indicator that suggest the solids composition is different at each location. This observation supports previous literature, with the influent solids being hypothesized to be more like primary solids and the effluent solids being more composed of less-settleable particles such as dead cellular debris as well as remaining wastewater solids.

### Biogeochemical Characterization Outcomes

The results from the biogeochemical characterization are referenced according to sampling locations within OP1 (Figure 23). Moisture content, volatile solids, nitrogen (TKN, ammonia, and nitrate), COD, BOD and CBOD, and NBOD are presented.

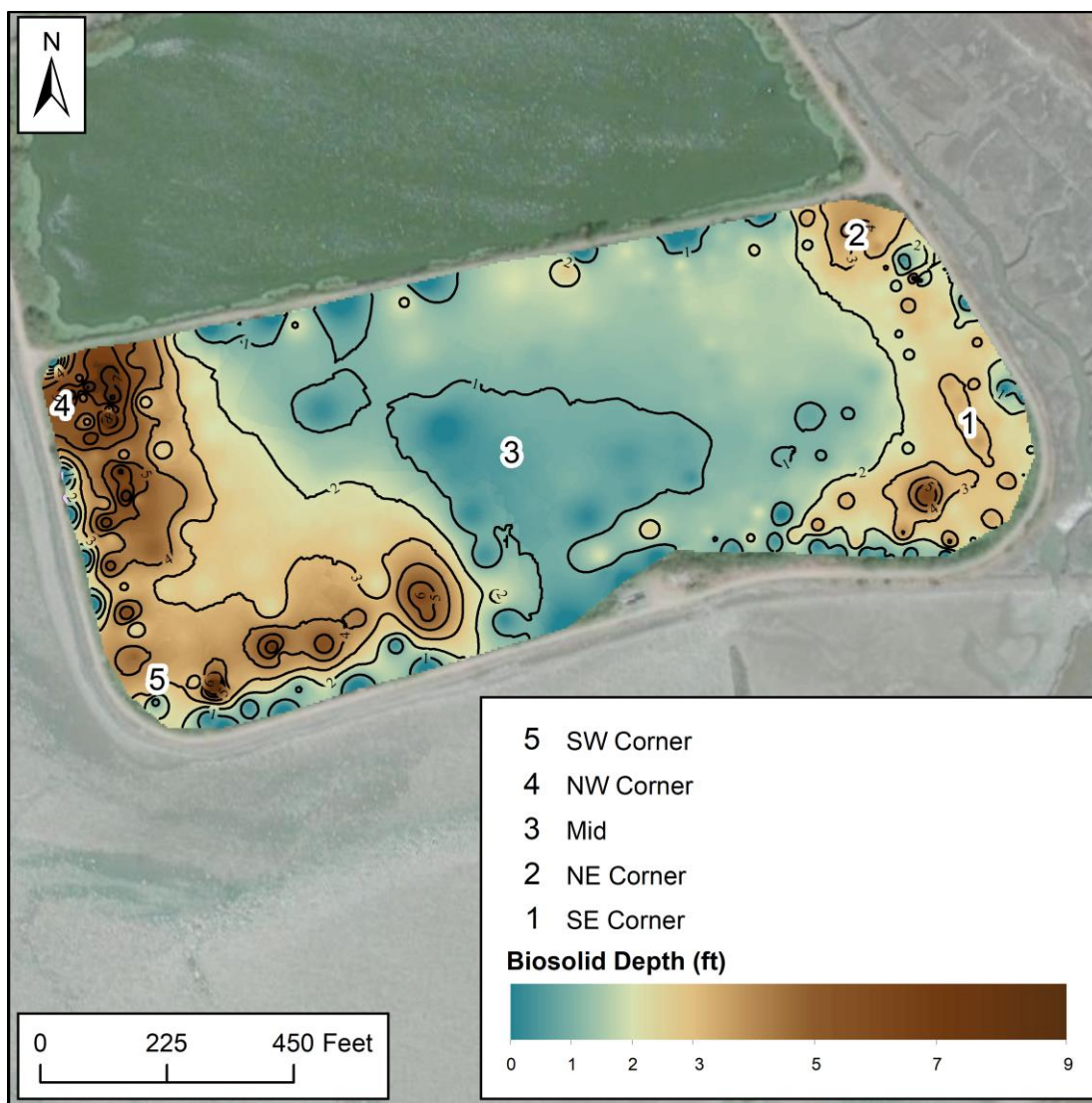


Figure 23. Biogeochemical characterization sampling points in reference to OPBS (1-ft contours).

Moisture content was found to decrease with depth and the bottom samples have lower percent moisture in the inlet (eastern) corners (Figure 24). The minimum, measured moisture content is 86%.

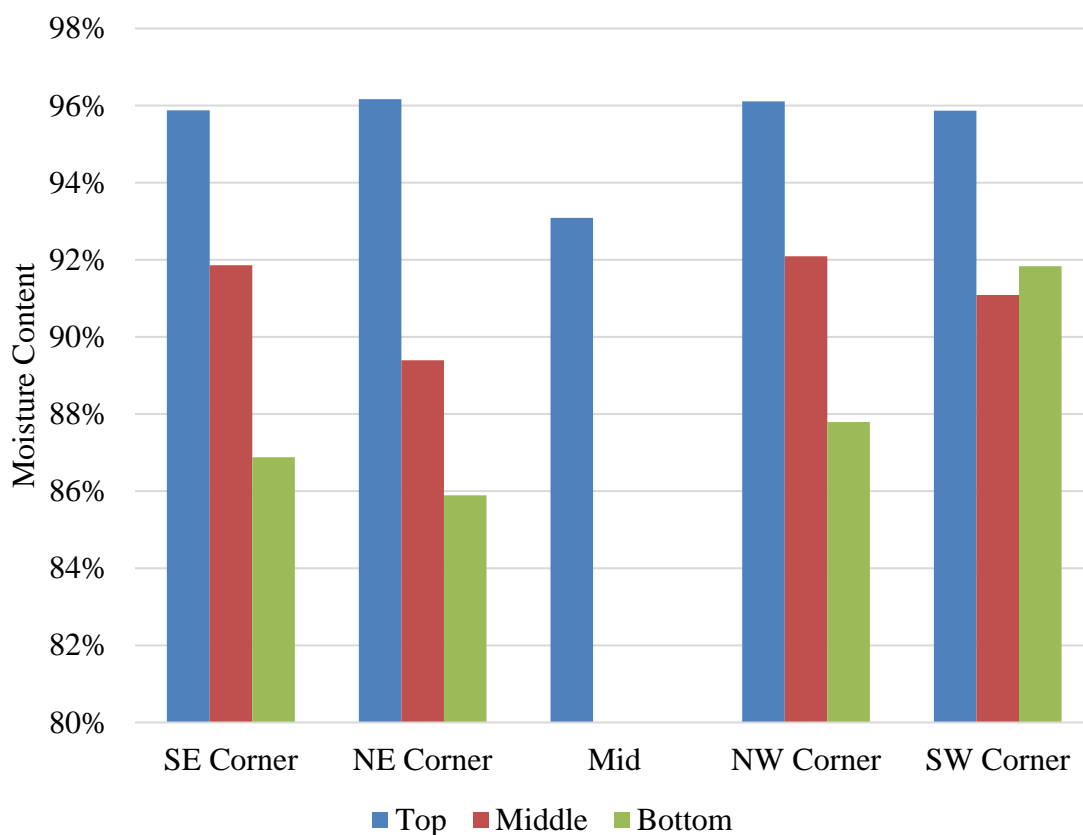


Figure 24. Moisture content variability over depth and area.

The volatile solids concentration within the pond are greater at nearly all depths in the inlet corners than the outlet (western) corners (Figure 25). The bottom sample from the southwest corner is unusually high. The NW and SE corners have the most distinct depth-gradients, with clear reduction in VS with depth. These locations also have the

highest solids/depth ratio (Figure 21). Except for the top layers, each OPBS sample was less than 50% volatile solids.

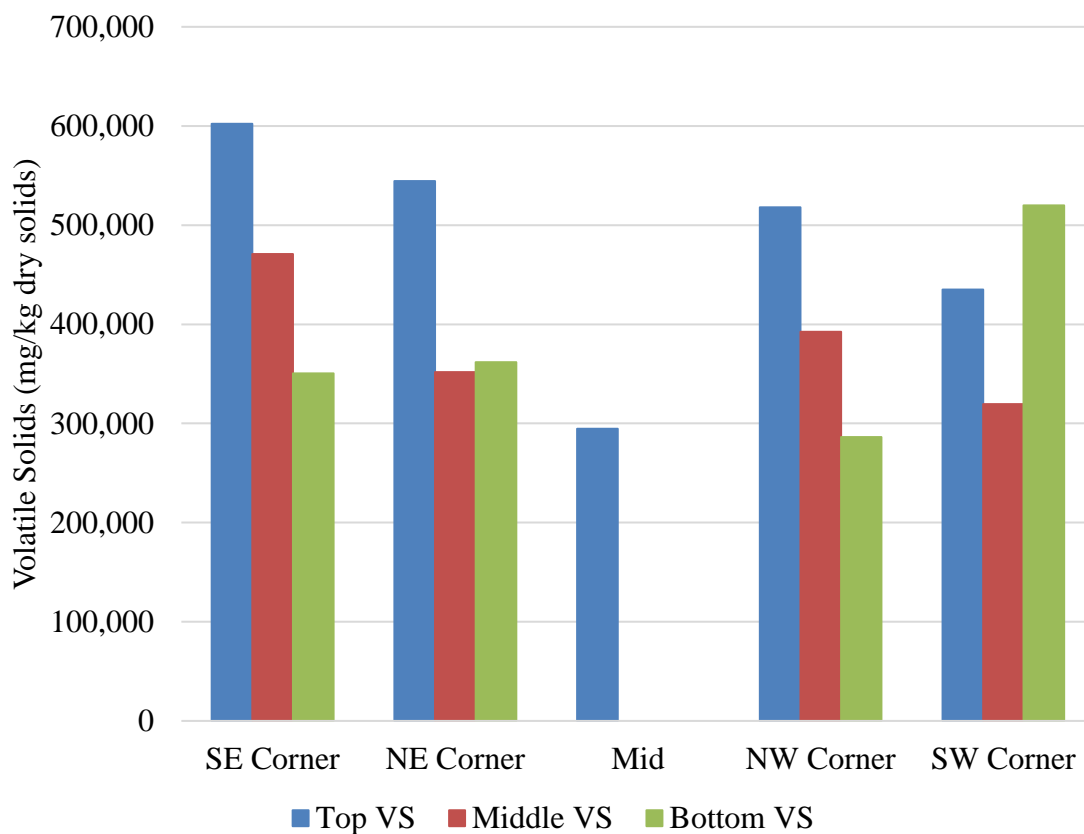


Figure 25. Volatile solids variability over depth and area.

The nitrogen concentrations of the measured species vary by orders of magnitude in OP1. The organic nitrogen component (TKN - Ammonia) is the most concentrated, followed by ammonia, then nitrate (Figure 26). For all species, nitrogen consistently decreases with depth and similar to solids concentrations there is a slightly greater concentration at the inlet corners.

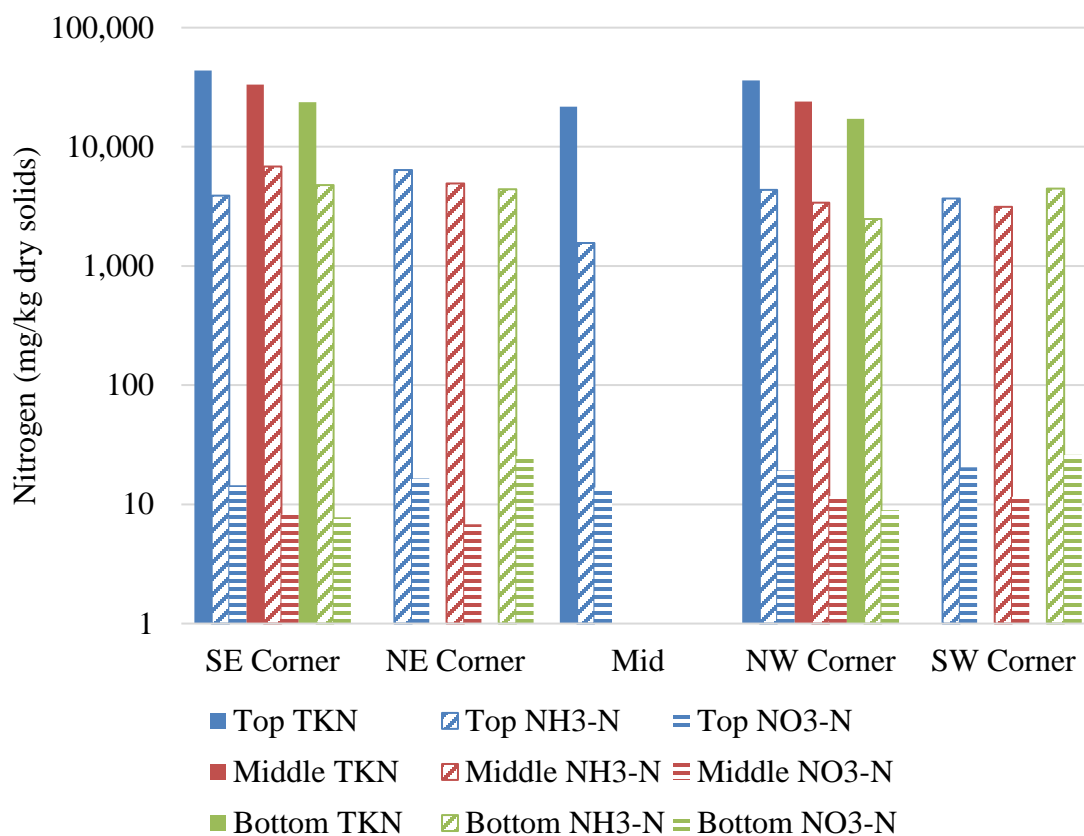


Figure 26. TKN, ammonia, and nitrate variability over depth and area.

The COD concentrations in OP1 closely match the trend of the volatile solids concentrations at each location and depth (Figure 27). Except for the outlier, southwest bottom sample, COD consistently decreases with depth. The decrease in COD concentration with depth follows a similar pattern as the volatile solids as well, but it is not as uniform. Using an average COD concentration across all depths and locations, along with the estimated mass of OPBS (Table 4), the total oxygen demand of the stored solids is approximately 5.28 million pounds of oxygen.

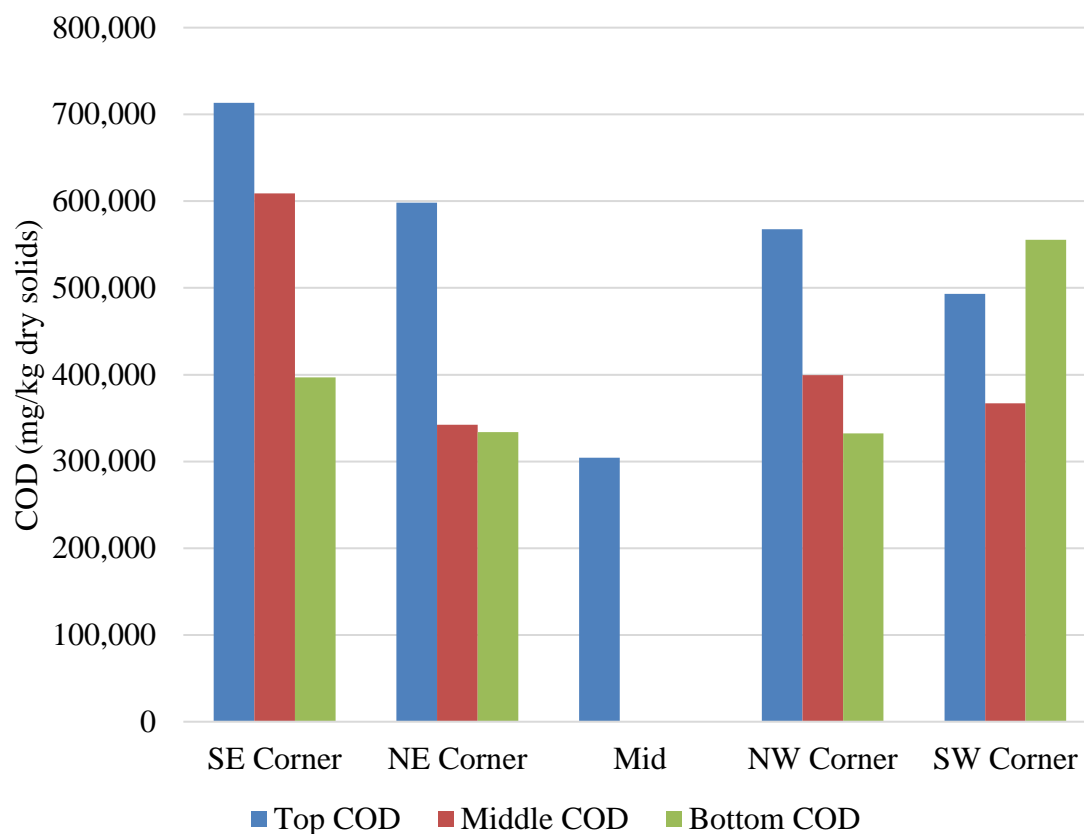


Figure 27. COD variability over depth and area.

Like the other parameters, BOD and CBOD decreases with depth (Figure 28). In the top samples, nearly half of the total BOD concentration is in the CBOD form. This ratio greatly increases at the mid and lower sections. However, the total amount of BOD at each location is only a fraction of the COD concentration. In the top samples, the BOD/CBOD ratio is less than 0.2 and at the bottom depths the ratio is less than 0.1. As depth increases the fraction of CBOD to BOD increases greatly.



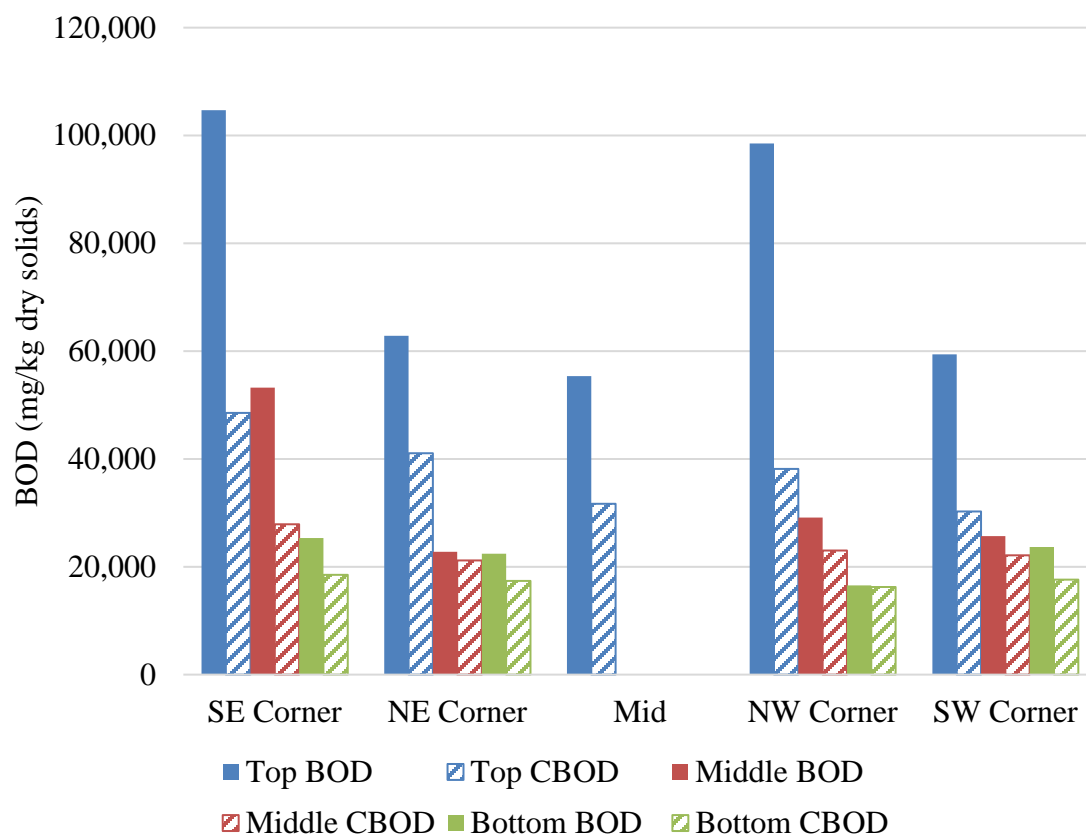


Figure 28. BOD and CBOD variability over depth and area.

NBOD is estimated using the difference between the measured BOD and CBOD as well as an estimate from the stoichiometry behind the digestion of organic nitrogen (Figure 29). There is a noticeably large difference between the two estimates with the organic nitrogen estimate being an order of magnitude greater.

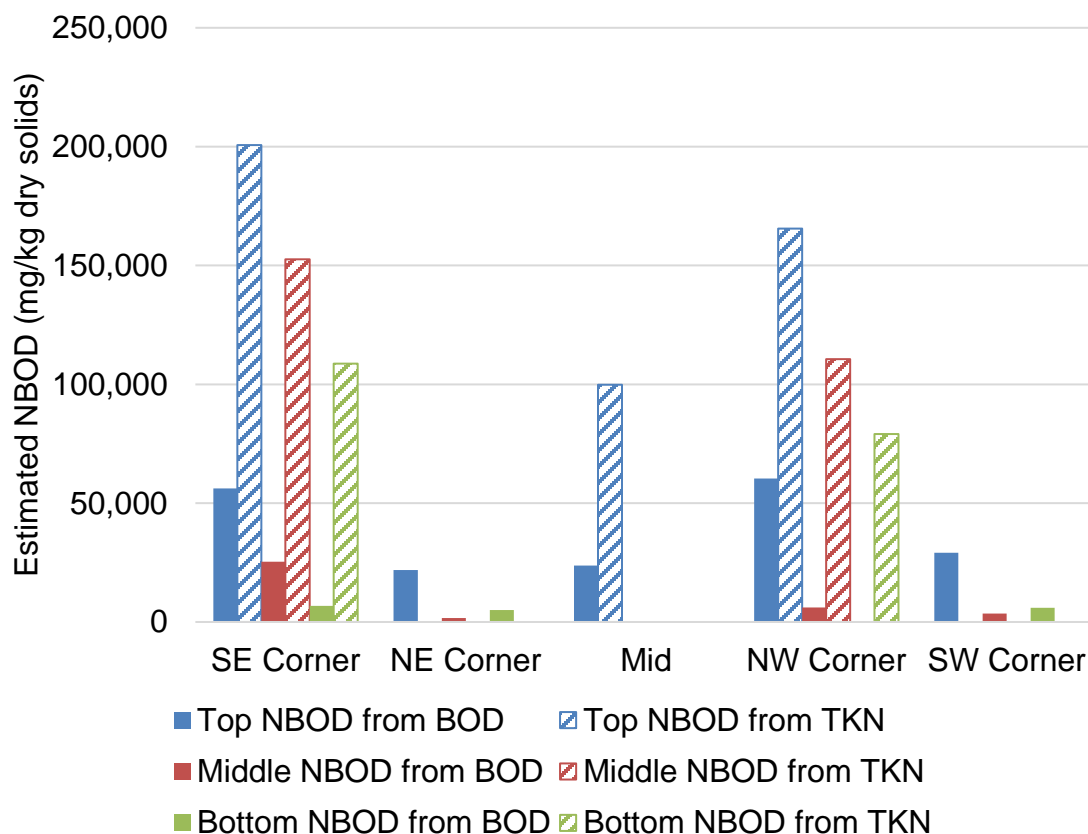


Figure 29. Estimated values of NBOD from BOD and TKN measurements at each location and depth.

The mass fraction of the constituents of concern for this project were examined for variability over the depth of the solids layer and for spatial variability over the pond area. On a mass by dry mass basis, all the constituents exhibited a similar pattern of a decrease in constituent concentration as depth into the solids layer increases. This agrees with literature data and indicates that the older solids are more degraded. COD, BOD, and TKN all decrease by over 40% between the top and bottom foot of solids. Also, the

moisture content of the bottom influent zones for this facultative pond matches very closely with literature values for anaerobic pond solids layers (Papadopoulos et al. 2003). An interesting trend in this data is that the concentration of volatile solids closely follows the concentration of COD over both depth and location, showing that the contaminants are associated with the solids themselves and not trapped pore water. This would indicate that reducing the amount of these volatile solids through treatment could not only improve hydraulic efficiency but also reduce the internal load. Also, the BOD, CBOD and TKN results show another trend. The reduction in BOD as depth increases is not equal to the reduction in CBOD. The CBOD concentration has a minimal change with depth while BOD and TKN results show a clearer decrease with depth. If CBOD doesn't change, but the total BOD and TKN show reductions the only component that could be responsible for the reduction are nitrogenous. This indicates that the nitrogenous component of the solids is the primary source of BOD and COD concentrations.

The spatial variability of constituents over the pond also reveals some noticeable trends. Spatially, the TKN in the influent (east) zone of the pond appears to have a higher concentration (approximately 30% more) than the effluent (west) zone. The TKN varies from 1%-4% of total solids mass, which is similar to published data (Schneider et al. 1984; Mtshali et al. 2014). Meanwhile, the COD and volatile solids concentration do not seem to be too spatially varied throughout the pond except for the southeast corner, which has elevated concentrations of both. This southeast corner is the also the location of max OPBS/depth ratio. The bottom layer values of COD and VS from the southwest corner do not make sense. The solids from this layer should be older than those above

them and therefore have had more time to digest and reduce both parameter values.

While there is not enough information to make a definitive statement, this value may be due to experimental error.

Regarding BOD, the northeast, mid, and southwest sample points of OP1 all have similar BOD mass concentrations even though the OPBS wet volume varies between these locations. However, the samples with the greatest wet volume of OPBS showed significantly greater BOD concentrations for their first layer of biosolids. This could be the result of the top layer of these sample locations having the freshest settled solids of the five sample points.

Besides their spatial and depth pattern, the BOD results appear to indicate some form of error. Based on the TKN, CBOD, and COD results, the BOD should be much larger. Assuming the kinetics for the removal of TKN requires approximately 4.6 times more oxygen than carbonaceous material, the amount of total BOD should be much greater than what was measured. The COD concentrations for each sample also indicate the BOD should be greater. However, using the measured CBOD and BOD values, the NBOD is much lower than the kinetic estimate (Figure 29). More research is needed regarding this subject, but this project assumes that the BOD contribution from nitrogen does not have enough time during the 5-day test to fully express itself.

After reviewing the data, it appears that the primary nitrogen contributing constituents are the TKN and remaining volatile solids. The TKN appears to be the primary driver for BOD and COD concentrations while the volatiles solids are closely related to the COD concentration. Using the same estimation method and assumptions

used for the spatial results, the mass of nitrogen in OP1 can be represented relative to the annual AWTF influent loading. For this estimation, contributing nitrogen species for the influent is ammonia and TKN for OP1. Because both of these parameters are expressed as masses of nitrogen (e.g.  $\text{NH}_3\text{-N}$ ) they can be directly compared. Assuming an average annual nitrogen load of approximately 247,000 lbs, the amount of nitrogen stored in OP1 (325,000 lbs) is roughly equivalent to 1.3 years of AWTF influent (Table 7). Assuming a constant loading pattern since 1986, this means that approximately 32 year's worth of nitrogen mass have been removed from the system by either transport or treatment. This amount of stored nitrogen would require nearly 1.5 million pounds of oxygen to completely treat (assuming 100% oxygen transfer). Also, using the assumed 30-year project life, this stored nitrogen equates to a recoverable capacity of approximately 800 people.

Table 7. Estimates of nitrogen mass in OP1 relating to time and population.

<b>Parameter</b>	<b>Value</b>
Estimated Nitrogen Stored in OP1 (lbs)	325,081
Oxygen Required for Treatment (lbs)	1,495,371
Average Annual TSS 1988-2018 (lbs/year)	246,563
Years-Worth of Stored Solids (year)	1.3
Average Annual TSS Load per Person (lbs/year/person)	14
30-Year Estimate of per Person Load (lbs/person)	411
Allowable Increase in Population (people)	791

The potential issues with treating this stored nitrogen and the volatile solids concentrations is the degradability of the OPBS. The BOD/COD ratios for each location is never greater than 0.2 at the “freshest” top layer of solids. Meanwhile, the bottom layers of solids show ratios that are less than 0.1. This is a major indication that the remaining volatile solids are recalcitrant material. If so, digestion of the OPBS would be more intensive and slower than material that is more biologically available.

### Treatment Options Outcomes

Results from the treatment trials are presented below. Figures include data from all six trials to illustrate trends in each parameter. For the COD results, trials 3 and 4 are excluded from figures due to errors in their analysis. Trial 1 has also been excluded from every plot (except ammonia and nitrate) due to its short sampling period in comparison to the other trials. Not having data up to the 40-day mark for trial 1 creates an abbreviated representation of its results and may lead to conclusions that cannot be supported. Also included in this section of results are the findings from the bench-scale aeration tests. The objective of this bench-scale test was to create replicate data for the pilot-scale reactors. While they did not ultimately provide this information, the results still have significance.

There was concern that the OPBS may act as an interference when measuring nutrient concentrations. However, the response of the ammonia and nitrate ion selective electrode (ISE) was linear as a sample of OPBS was diluted with deionized water (Figure 30). Also, the slope of each ISE curve is near equal to the non-dilute sample

concentration confirming that results from the ISE are not biased by OPBS for these nutrients.

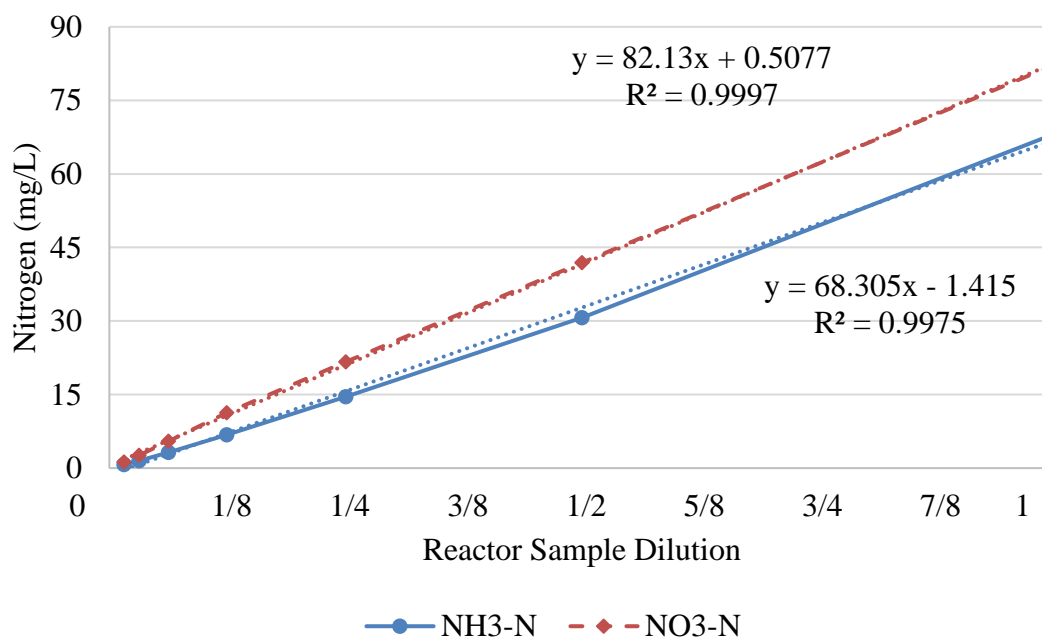


Figure 30. Response curve of ammonia and nitrate electrode probes with OPBS dilutions.

The volatile solids in each reactor, except for trial 1, increased in concentration as aeration occurred (Figure 31). It should be noted that the two trials that are the most different (1 and 2) are the experiments that were operated outdoors, experienced greater temperatures, and were not alkalinity controlled. Trials 3-6 averaged an 18% increase VS, with trial 5 having the largest increase with 32%. Trial 1 experienced a minor reduction (4%) and Trial 2 remained near its starting concentration with only a 1% increase.

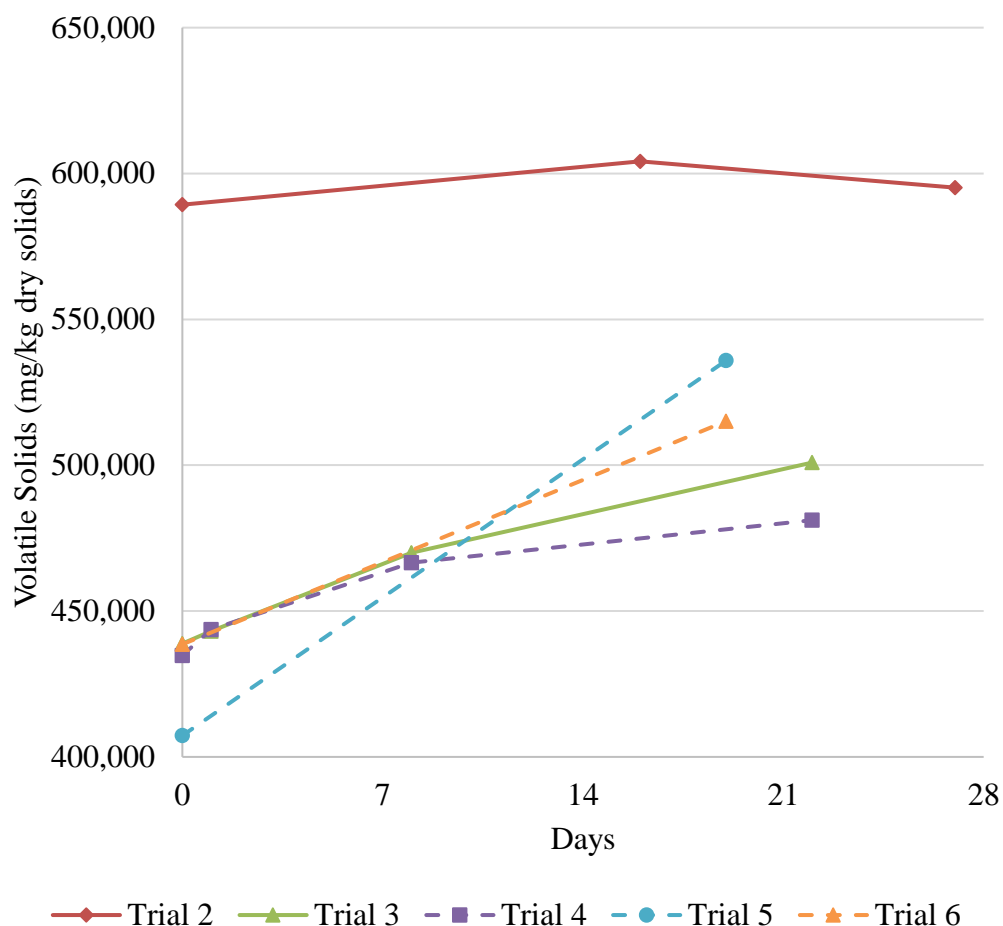


Figure 31. Volatile solids concentrations throughout each trial.

All six trials of ammonia and nitrate followed a similar pattern to one another. Ammonia was quickly removed in the reactors, with minimum or near-zero concentrations consistently occurring between the 10- and 13-day mark (Figure 32). Trials 1 and 2 were the only reactors to never reach a near-zero concentration but still experienced their lowest concentrations at that time. This was most likely the same time that alkalinity in each reactor reached a concentration that could not support nitrification



at a rate equal to or greater than mineralization. The low pH values recorded during this time ( $< 5$ ) and the increase in ammonia concentrations support this argument.

Nitrate concentrations started increasing immediately, but not at as high a rate as the ammonia removal. Nitrate continued to increase throughout each trial period, however the rate of increase tapered off around the same time that ammonia concentrations reached their near-zero values (Figure 33). After this point, nitrate concentration would continue to slowly increase overall but experience occasional decreases as well (which could potentially be instrument error). An important trend in the ammonia and nitrate data is that the rate of ammonia removal is not equal to the rate of nitrate production. Nitrate production does not occur significantly until several days after major decreases in ammonia concentration (Figure 34). After reaching their minimum ammonia concentrations, trials 1 and 2 both experienced an increase in ammonia. As aeration continued past this point, both the ammonia and nitrate concentrations increased.

In an attempt to create multiple replicates of the ammonia and nitrate patterns, bench-scale bucket tests were monitored (Figure 35). In this experiment, the bucket reactors removed ammonia in a similar fashion to the pilot-scale reactors, with the lowest recorded concentrations occurring at the last sampling day (day 12). However, unlike the pilot-scale reactors, the nitrate response was minimal with the largest recorded concentration being 8 mg/L, which occurred after an ammonia reduction of approximately 90 mg/L. An additional bucket system was started at a later date to track the nitrite concentration during the first 5 days of aeration. The results of that experiment showed non-detect concentrations for every analyzed sample (Appendix B).

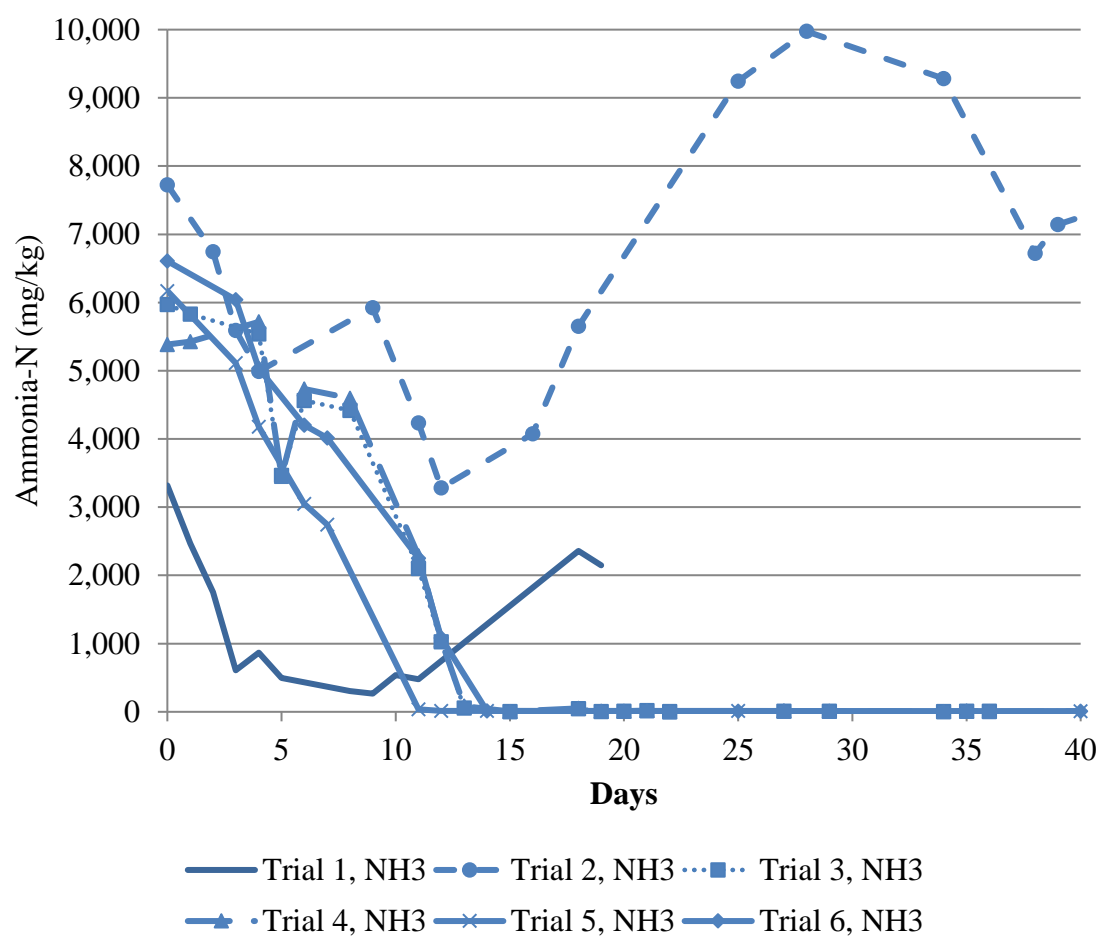


Figure 32. Ammonia concentrations throughout each trial.

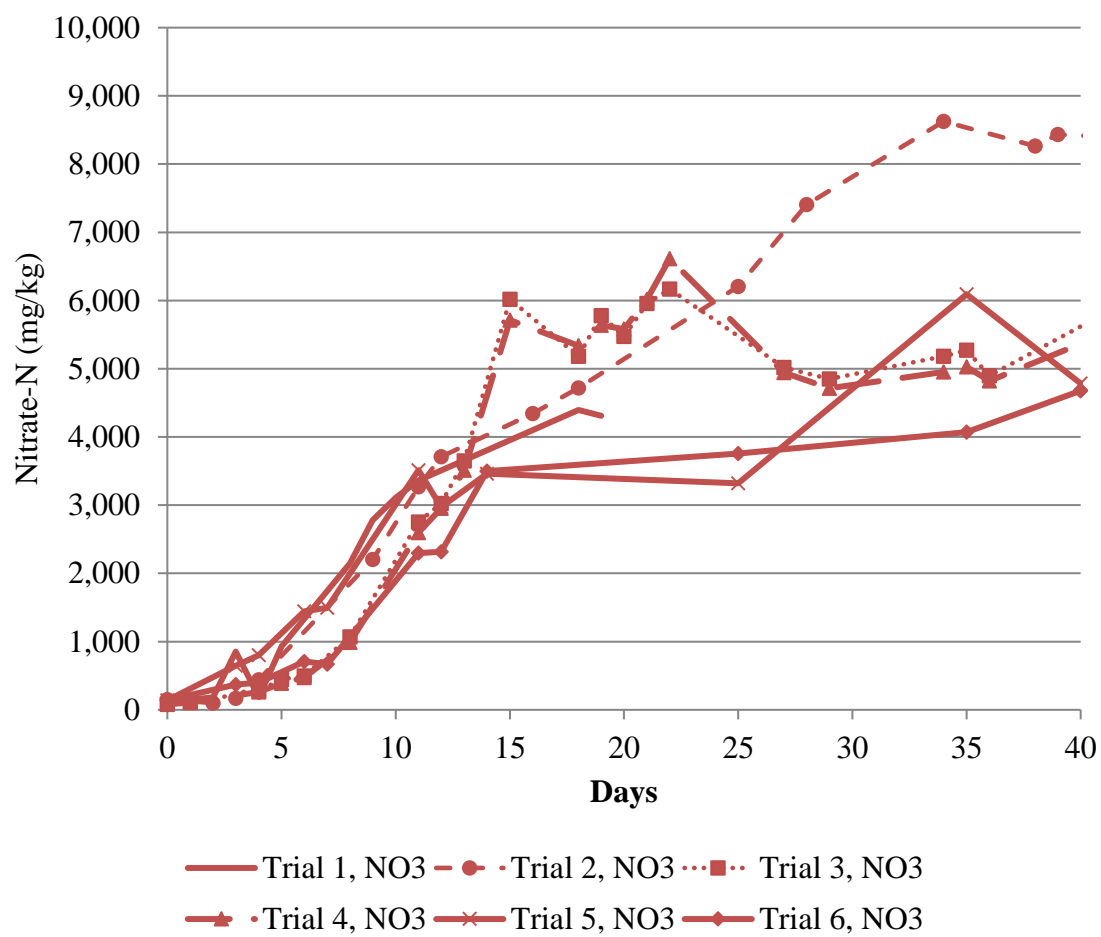


Figure 33. Nitrate concentrations throughout each trial.

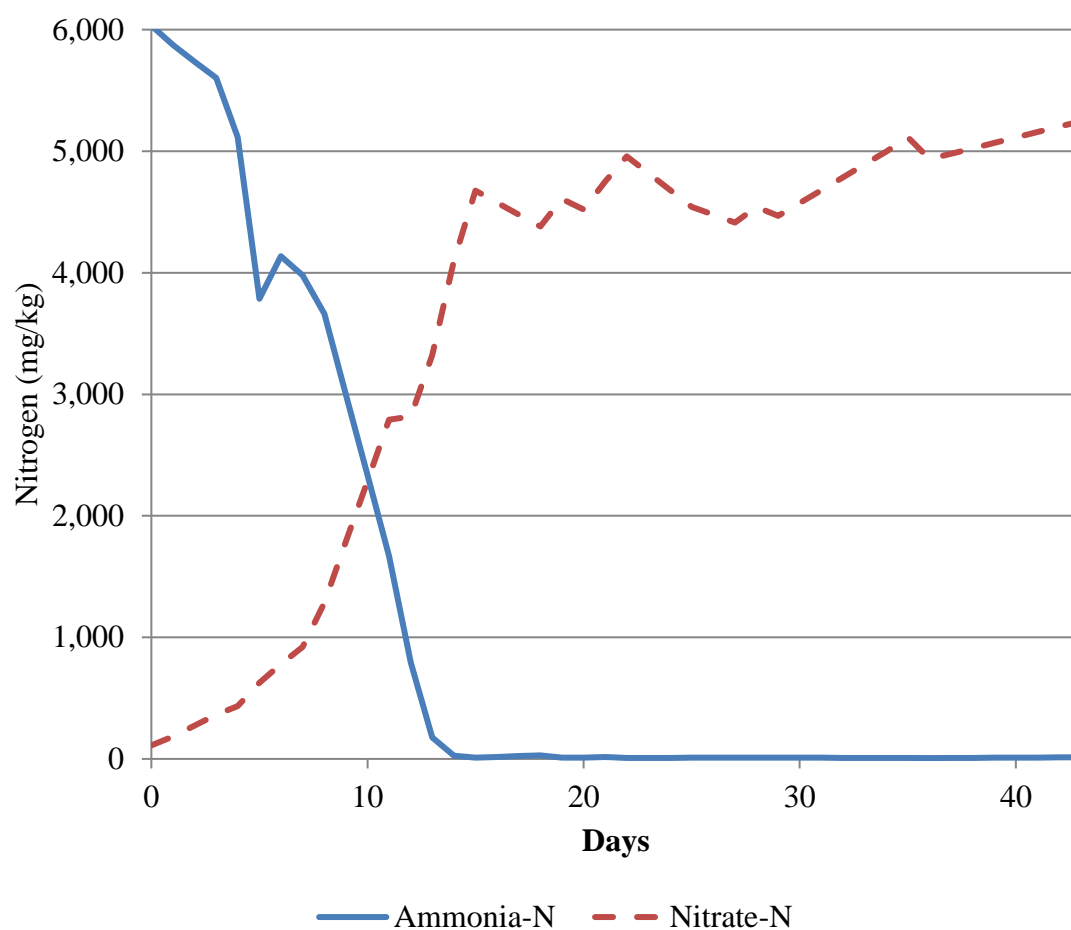


Figure 34. Average ammonia and nitrate concentrations for trials 3-6.

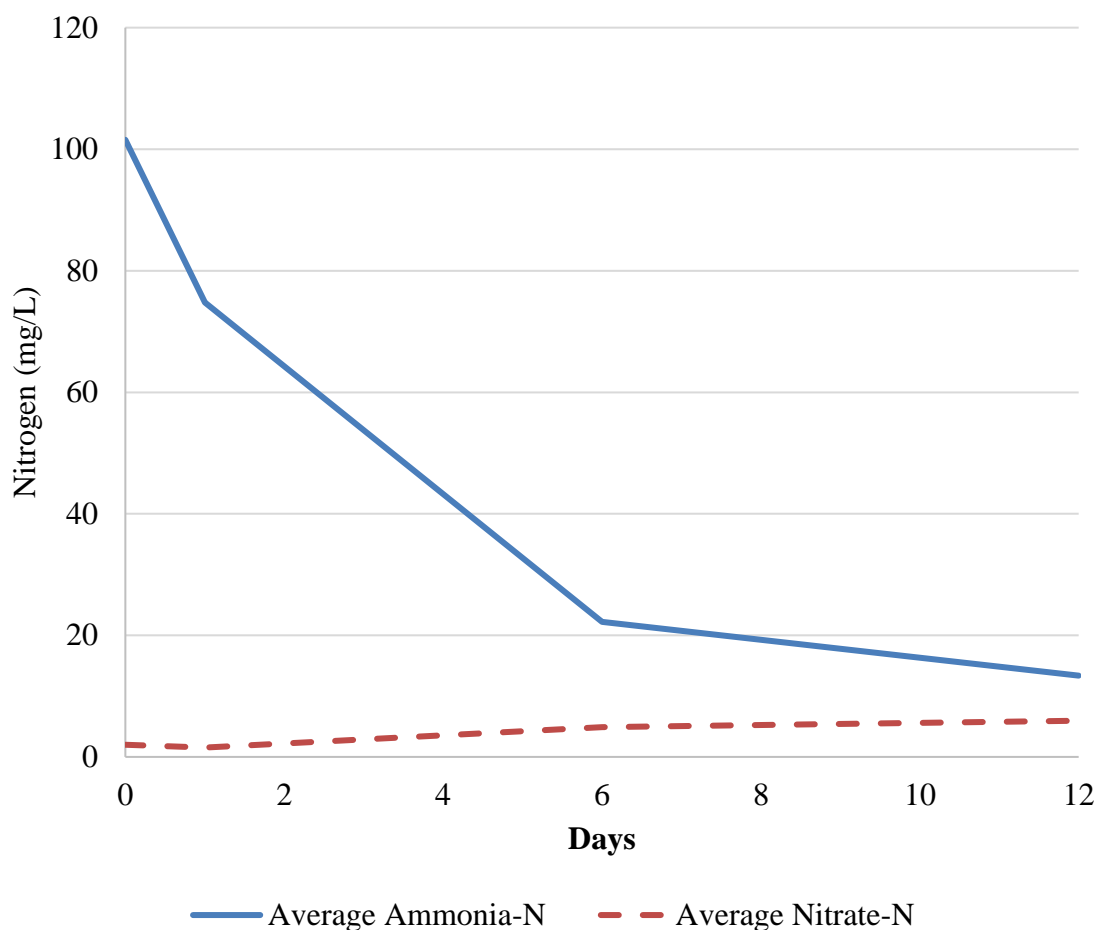


Figure 35. Average ammonia and nitrate concentrations for bench-scale aeration.

The results from the bench-scale experiment reveal an important relationship between the ammonia concentration and the stored OPBS. Each of the five bucket trials in this experiment experienced a significant reduction in ammonia concentration with only minor increases in nitrate concentration. The aeration in this experiment was sufficient enough to keep DO concentrations in the aerobic zone but was not strong enough to keep the OPBS suspended. As a result, the OPBS in each bucket settled to the

bottom. At the end of this experiment the buckets were manually mixed to resuspend the OPBS and sampled to measure ammonia and nitrate. The results of those tests revealed that ammonia was still present in high concentrations. This indicates that the ammonia in the OPBS is fixed to the solids themselves (or trapped in the void space of the OPBS) and not freely available in the bulk liquid volume. This conclusion means that aeration alone may not be effective for nitrogen removal in the OPBS because only a fraction of the stored nitrogen appears to naturally release to the liquid volume. This finding also supports the theory of pond turnover being responsible for seasonal ammonia spikes at the AWTF. During the periods of ammonia spikes solids are observably suspended in OP1.

The COD response across the three recorded trials (2, 5, and 6) was inconsistent (Figure 36). Trial 6 experienced an 11% COD reduction while trials 2 and 5 saw larger reductions (44% and 45%, respectively). The initial COD concentration was also widely variable, with trial 2 being an order of magnitude greater.

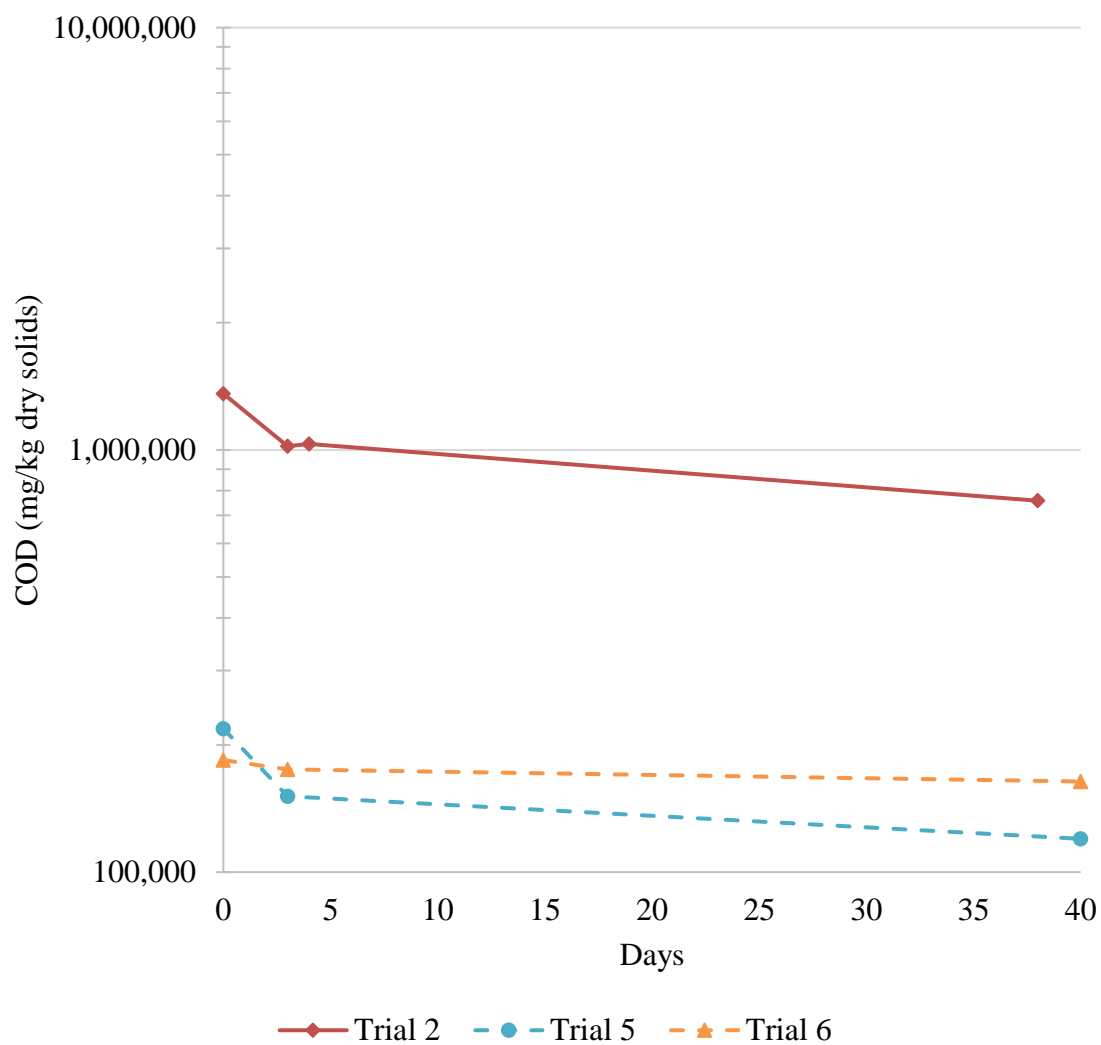


Figure 36. COD concentrations throughout each trial, excluding trials 3 and 4.

The BOD concentration response was inconsistent, similar to the COD response. Trials 3 and 4 experienced minor overall increases in concentration with an average 3% change while trials 2, 5, and 6 experience significant overall decreases in concentration (44%, 67%, and 65%) (Figure 37). Trials 5 and 6 also experienced a significant drop in BOD concentration in the three-day period of day 3 to 6.

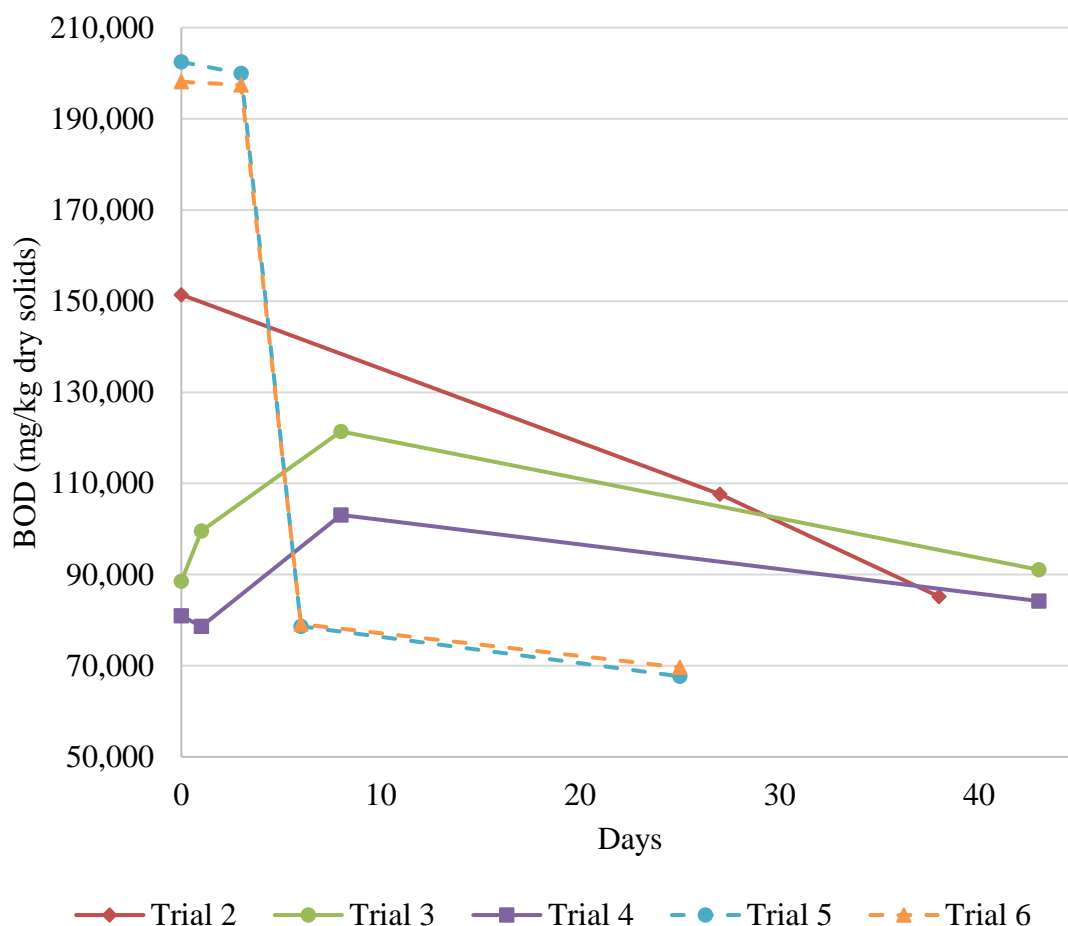


Figure 37. BOD concentrations throughout each trial.

For CBOD and SBOD, trials 2-5 experienced large reductions in concentration.

Trial 2 experienced the lowest total reduction in CBOD with an 18% change. Trials 3-6 saw an average of 59% CBOD reduction (Figure 38). Meanwhile, the average SBOD removal was 82% (Figure 39). The reduction trend of the SBOD resembles the plateau of the ammonia removal from Figure 34.



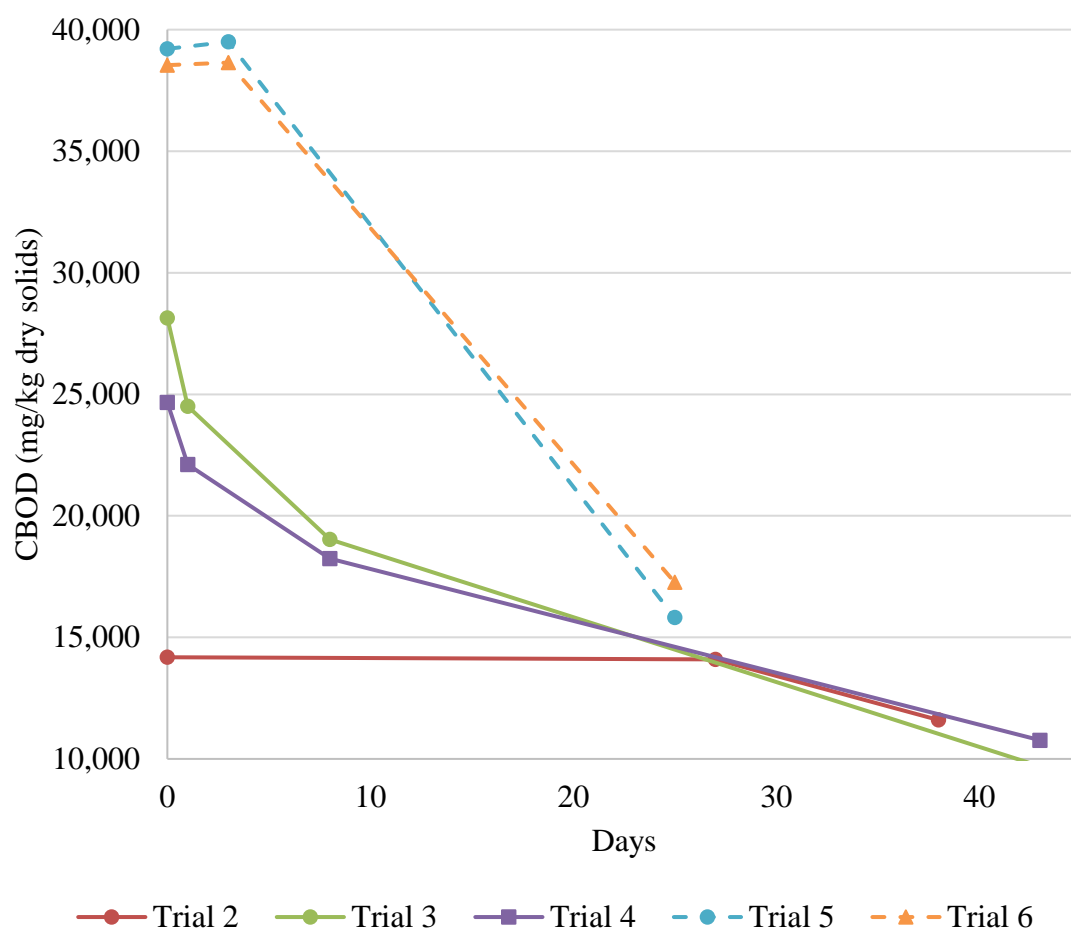


Figure 38. CBOD concentrations throughout each trial.

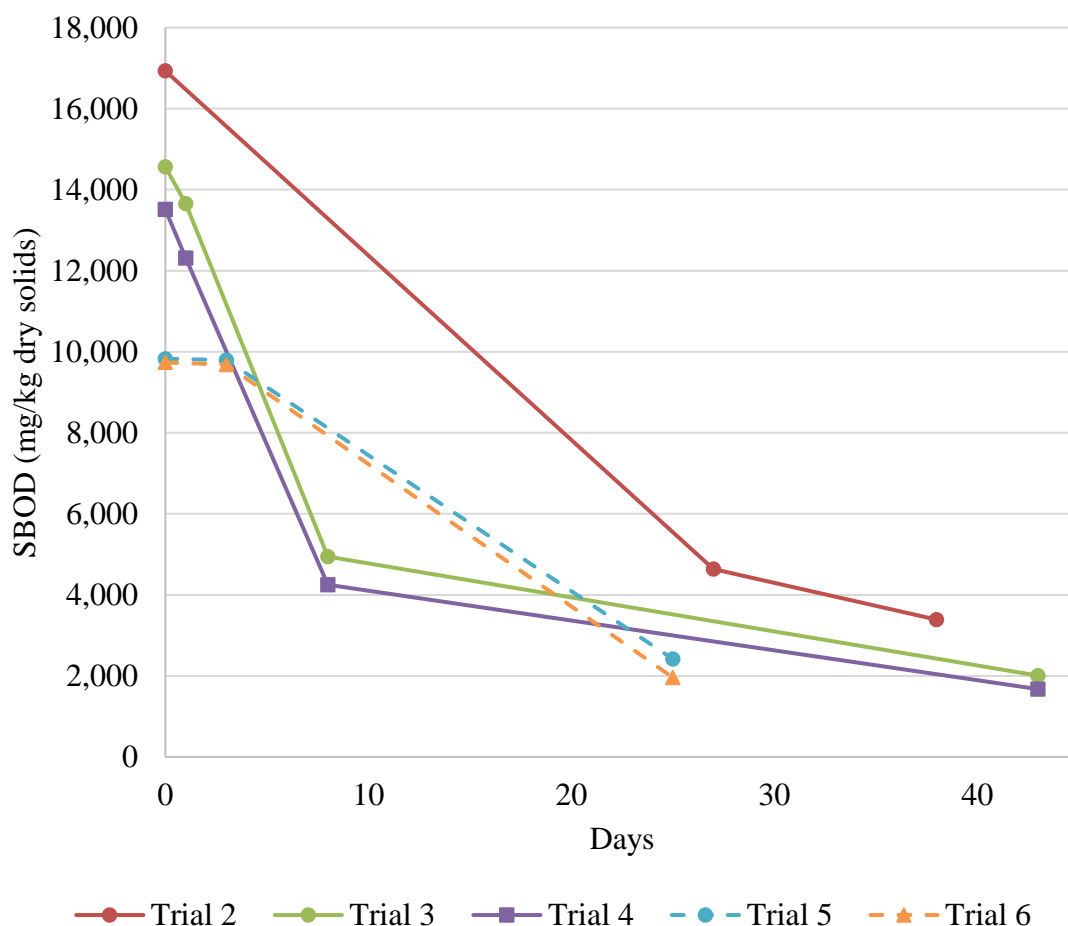


Figure 39. SBOD concentrations throughout each trial.

The results of aeration's effect on the OPBS indicate that it may be a viable option for the AWTF, but based on the biogeochemical results, the OPBS appear to be recalcitrant material that could be resistant to digestion. These conflicting results are compounded by the results of the VS, COD, and BOD. For example, regarding VS, five of the six trials experienced an increase in concentration with time. While some of this result may be contributed to the new population of bacteria, it's difficult to argue that

32% (in the worst case) is solely caused by microbes. What may be happening instead is the settling of denser, sediment particles in the reactor and are removed from obtained samples. While the reactors are mixed from the bottom for maximum suspension, once a particle falls below the aeration disk (bottom 3 inches of the reactor) it may be difficult for it to resuspend. Accumulation of  $\text{CaCO}_3$  were noted below the aeration disk when the bulk water of the reactors was removed, supporting the hypothesis that denser particles were capable of settling with the experimental mixing regime.

Half of the reactor trials experienced significant reduction for COD and BOD (average of 45% and 58%, respectively) while the other half experienced little to no reduction (average of 13% and 3%, respectively). However, in all instances the CBOD and SBOD components experienced major reductions (average 59% and 80%, respectively). This indicates that easily available organic material (SBOD) is consistently treated, which does have an impact on the overall BOD and COD concentration. However, the total reduction in BOD for each trial is not completely accounted for by the CBOD reduction, indicating a major reduction in the nitrogen load of the OPBS. Also of note, is the large decrease BOD between days 3 and 6 for trials 5 and 6. This sudden reduction is not accounted for by the ammonia reduction as ammonia reduction at that time was on par to the other trials.

The most interesting data trends during treatment came from the nitrification process (Figure 34). First, an unexpected trend appeared while monitoring the inorganic nitrogen concentrations of the first treatment trial. Within the first four days, the ammonia concentration within the reactor plummeted signaling that nitrification was occurring.

What made this pattern strange was that the nitrate concentrations were not rising at the same rate. In all six trials, the ammonia concentration decreased rapidly when aeration began, but the expected increase in the nitrate concentration from the nitrification process lagged by four to five days. This would suggest a few possible scenarios:

1. The ammonia is not being nitrified, rather it is being volatilized by high pH conditions.

This possibility is unlikely since volatilization only occurs in very basic conditions and the pH of the reactors was always below 8.

2. The ammonia was being directly converted to nitrogen gas through an anoxic process like anammox.

This explanation is unlikely since the anammox process requires anoxic conditions and the DO concentrations throughout the reactor was always measured to be above 2 mg/L.

3. Denitrification is occurring at the same rate as nitrification during the first days of aeration.

This explanation is unlikely for the same reasons as anammox. While aerobic denitrification is a documented process, there is no way to prove this pathway without a microbial inventory.

4. The second step of the nitrification process takes longer to become established than the first step. Nitrification is a two-step process where one bacterial group (Nitrosomonas) converting the ammonia to nitrite and another bacterial group (Nitrobacter) converting this nitrite to nitrate. The large amount of introduced nitrogen (as ammonia and organic nitrogen) is making favorable conditions for mineralizing bacteria and Nitrosomonas only.

Normally nitrite does not exist for any significant amount of time in natural waters. The results from the contracted analytical lab revealed as much with the non-detect measurements for nitrite. These non-detects may have been caused by nitrite conversion during storage and shipping. As of the conclusion for this project, no adequate reason for these results is available. Describing the exact process occurring in the nitrogen cycle is outside the scope of this project, but it does pose a future research question.

Another interesting result from these trials is what happens when calcium carbonate was added to maintain sufficient alkalinity. For trials 1 and 2, alkalinity was not controlled, which allowed the reactor to reach pH values as low as 4.5 within two weeks. At that point of treatment, ammonia would start to “reappear” in the system, indicating another “source”, however this was not observable in the trials with controlled alkalinity. From the results of the TKN in the OPBS, there is an abundance of available nitrogen to be reintroduced as ammonia through mineralization. Since the accumulation of nitrate still occurs with the reintroduction of ammonia, it is hypothesized that the low pH conditions accelerate the mineralization process and make the nitrification process the limiting reaction. If this were not the case, then ammonia would not increase along with

the nitrate. Meanwhile in the alkalinity-controlled trials, once the ammonia concentration is near zero, it does not experience a noticeable re-introduction. In this case it is assumed that mineralization is the limiting reaction and any re-introduced ammonia is quickly converted to nitrate.

For trials 3-6, pH was held in the 7.0-7.5 range (barring a span of two days where the pH dropped to 6.0 for trials 3 and 4) using calcium carbonate. With the pH controlled, the ammonia concentration essentially went to zero at approximately two weeks into the experiment. Instead of the ammonia spiking to high concentration like the previous trials, it remained at zero. However, the nitrate concentration continues to climb indicating that there is still available nitrogen to convert, but that the rate of nitrification is greater than or equal to the rate of ammonia reintroduction (through either solubilization or mineralization).

The reaction rates for trials 3-6 may not be directly comparable as they had different environmental and operating conditions (primarily temperature). Temperature is a major factor in most biological and chemical kinetic models and changes of 10 °C have the potential to half the reaction rate of a given process. Without a method of controlling the temperature, reaction rates likely have varied during and between trials. Trials 1 and 2 did not have pH control and they also occurred from the early to mid-fall season where temperatures were still above 15 °C. Meanwhile, trials 3-6 were pH controlled but they occurred mid-winter when the average water temperature had been less than 12 °C (reaching as low as 7 °C).

The use of added alkalinity adds an operational consideration for aeration implementation at the AWTF. If aerators are installed and operated at all times the pond may reach a point of insufficient alkalinity and create unfavorable, low-pH conditions. This can be potentially avoided with one of two operational controls. The first control is an obvious alkalinity addition similar to the pilot-scale tests done for this project. This would require an additional chemical treatment method and all the operational issues associated with it (storage, training, maintenance, etc.). The second control would be custom-controlled aeration times that utilize the aerobic environment for nitrification and then stop the aeration but continue mixing to create an anaerobic environment for denitrification. By staggering between the two processes, some of the existing alkalinity can be recycled.

The results of this project are specific to AWTF. During the literature review portion of this project, it was discovered just how location sensitive OPBS are and their characterizations should reflect that. Like all facilities, AWTF's construction, historical operation, climate, and influent sources create a biosolids system that is unique. However, things such as sampling techniques and chemical analyses are near universal in their application. Nearly all facilities would be capable of performing a solid survey identical to the one presented in this project as it relied on a simple, low-cost, manual measurement. The specific use of ArcGIS and the laboratory analysis may be more restricted, but suitable alternatives could be implemented. Geometric estimation could be used for volume estimates and spot tests of certain water quality parameters could be used to reduce costs.

## CONCLUSIONS AND RECOMMENDATIONS

The 253-sample point OPBS survey performed for this project built upon previous OP1 surveys and provided more details about the distribution of solids. With a new sampling device and an extensive sampling grid, this is the first survey done in OP1 that accounts for the deep borrow pits found along the western edge. The OPBS distribution pattern observed in this project matches the results from a 2008 survey while estimating nearly double the total wet OPBS volume ( $62,000 \text{ m}^3$ ). The southeastern corner of OP1 is the most impacted area, experiencing upwards of 90% of the volume being occupied by OPBS. The northwestern corner has the deepest total depth area (up to 12 ft) and the deepest solids depth (up to 9 ft). The hydraulically active mid-section of OP1 has a uniform, low volume of solids. Sampling resolution does affect the volume estimate but only by a small fraction. Reducing the sampling by 50% only reduced the volume estimate by 10%. For future, surveys (OP2, treatment marshes, or enhancement wetlands) this knowledge can save sampling time and operation costs.

The results of the composition characterization revealed several key conclusions. Stratified samples were taken at five different points of interest in OP1. The purpose of this sampling method was to measure spatial differences in the horizontal and vertical planes. The concentration of pollutants is stratified by depth, with concentrations decreasing as the depth increases. This result makes logical sense, as the depth of solids corresponds to the time spent in OP1. The characterization also showed that the majority of the measured oxygen demand from the OPBS appears to originate from organic



nitrogen. This pattern is a result of the BOD being less than 20% of the COD concentration (at most) and the BOD measurement seemingly not including the nitrogenous component. This indicates that the organic nitrogen is not being digested during DO limited periods, such as a 5-day BOD test.

Treatment results were obtained using aeration reactors that provided a constant excess airflow that kept the DO of samples in the aerobic zone. Aeration reduced all measured pollutants except for VS, which increased. Ammonia and nitrate followed a consistent pattern of removal and production, respectively. A key conclusion to note is that sufficient alkalinity must be present for the rate of nitrification to compete with the rate of mineralization. Another key conclusion regarding nitrogen, is that it appears that the ammonia in the OPBS system is tied to the OPBS itself. If the solids settle out, there is a major, observable decrease in ammonia concentration with no corresponding increase to nitrate. To properly treat the OPBS, they must remain suspended and aerated. BOD and COD concentration varied by trial, however the CBOD and SBOD of each trial consistently decreased with aeration.

In conclusion, the biosolids at the AWTF are occupying a large volume of space in OP1 and while portions of these solids are over 30 years old, they are still high in pollutant concentrations. The wet OPBS occupy nearly 40% of the total pond volume and the mass stored is equivalent to over eight years of raw wastewater influent. Meanwhile the nitrogen stored in these solids is estimated to require over 1.5 million pounds of oxygen to facilitate digestion. While this number is a rough estimate due to major

assumptions (e.g. 100% transfer rate and digestion efficiency) the treatment trials of this project have shown that nitrogen reduction is achievable.

### Recommendations

The results of this project suggest several topics for future or continued study as well as two recommendations for treatment options. For future studies, an inventory of the bacteria in the OP and/or aerated system would provide more information regarding the processes and kinetics of biological digestion. The exact process of nitrogen removal presented in this project cannot be explained with the collected data. Having a better understanding of the conditions that cause this process could lead to the ability to target its use for future treatment. For example, if bacteria responsible for the majority of conversion were inactive during low temperatures then aeration could be stopped. Also, the effect of resuspended solids should be studied as soon as aeration is implemented. Monitoring the suspended and total solids of the influent and effluent of OP1 would allow for an estimate of the mass of solids leaving the system. Tracking the potential transport of OPBS is vital in regards to its treatment.

For operation recommendations, the primary recommendation of this report is to implement aeration in OP1. Internal loads can be reduced *in-situ* for a fraction of the cost of additional infrastructure. This project recommends that several of any planned aerators be installed in locations of greatest OPBS accumulation such as the eastern and western borders. Based on the results of the bench-scale experiment, concentrating the aerators in the low OPBS volume mid-section of OP1 would not allow treatment of the nitrogen

attached to the majority of stored OPBS. While aerators in the mid-section would keep the OPBS suspension, the high-impact areas need their own aerators to suspend their stored solids. Once aeration is installed, an optimal aeration schedule would be required. Determining how long aeration and non-aeration cycles should last to maximize the recovery of alkalinity and reduction of nitrogen is necessary. The results of this project's aeration experiments show that alkalinity is a requirement for adequate treatment. Chemically dosing OP1 may be avoided if alkalinity can be sufficiently recycled through denitrification while the aerators are inactive. Additionally, the aerators must be capable of keeping the OPBS suspended. The results of the bench-scale tests indicate that suspension is key to the treatment of stored nitrogen. A monitoring plan is also recommended to be implemented for all parameters of concern: ammonia, nitrate, TKN, alkalinity, TSS, pH, and temperature. COD and BOD could also be monitored to see if any clear long-term patterns become observable.

The second operational recommendation is an alternative treatment strategy to aeration. Reducing the wet volume of the OPBS and redistributing them across the pond may have operational benefits. Dewatering OP1 until the OPBS are exposed to sun can be achieved by taking the pond offline during low flow periods (summer) and allowing the liquid volume of OP1 to be metered into OP2. As the water level in OP1 decreases, the OPBS would be redistributed (either naturally by atmospheric pressure or machine-facilitated) throughout the pond area. If the OPBS were to be concentrated through evaporation, it would make transport to a landfill or dedicated aeration basin more effective. Even if the OPBS were not removed from the pond, pond drainage could

achieve several possible outcomes. First, the solids would be more compact and better distributed, recovering some of the lost pond capacity. Second, if OP1 were offline it would not produce as many algal solids that could contribute to the fresh layer of OPBS in itself or OP2. Third, if OP1 is not drained but still offline and aerators are installed, OP1 would essentially act as a large batch reactor, which would reduce potential solids transport downstream and allow for better control of alkalinity and any potential treatment byproducts.

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## Appendix A - ArcMap methodology Visual Guide

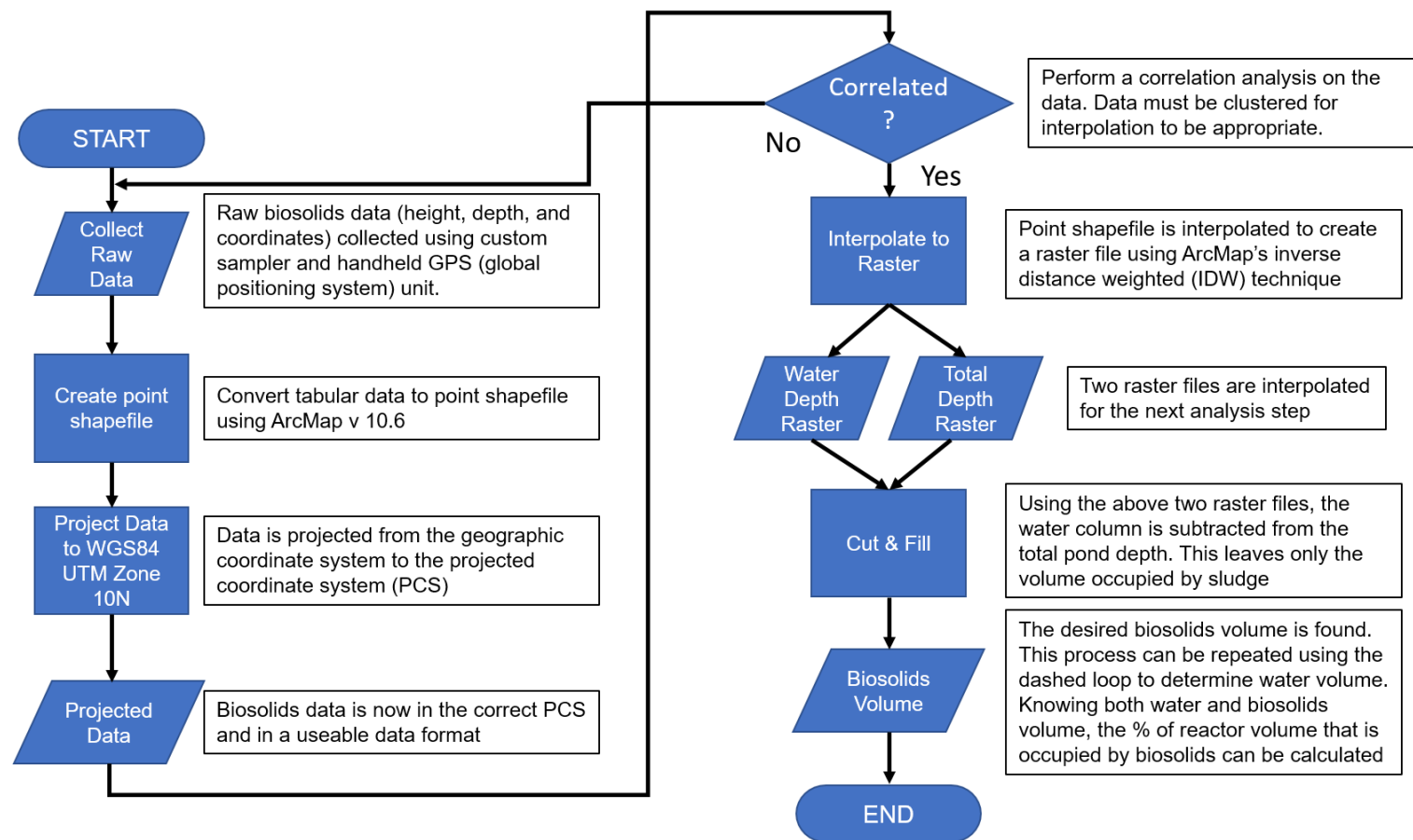


Figure A-1. Process for ArcMap data analysis.

## Appendix B - Analytical Laboratory Results



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ELAP Certificates 1551, 2728, 2922, and 2303

28 December 2018

Humboldt State Univ - Env. Resources & Engineering

Brad Finney

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Enclosed are the results of analyses for samples received by the laboratory on 12/18/18 09:10. If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Jeanette L. Poplin For David S. Pingatore  
Project Manager



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Humboldt State Univ - Env. Resources & Engineerin  
1 Harpst Street  
Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

**Pt. 1.1****18L2248-01(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	1800	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

**Pt. 1.2****18L2248-02(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	2700	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Humboldt State Univ - Env. Resources & Engineerin	Project Manager: Brad Finney	Reported:
1 Harpst Street		12/28/18 14:03
Arcata CA, 95521		

**Pt. 1.3**

**18L2248-03(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	3100	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Project Manager: Brad Finney

Reported:  
12/28/18 14:03

## Pt. 3

## 18L2248-04(Soil)

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	1500	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Reported:  
12/28/18 14:03

**Pt. 4.1****18L2248-05(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	1400	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

**Pt. 4.2****18L2248-06(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	1900	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

**Pt. 4.3****18L2248-07(Soil)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Conventional Chemistry Parameters by APHA/EPA Methods											
Total Kjeldahl Nitrogen	2100	2.0	10	mg/kg	1	AL84169	12/20/18 14:21	12/21/18 14:59	SM4500-Norg	B	

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Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

## Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	MDL	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
<b>Batch AL84169 - General Prep</b>											
<b>LCS (AL84169-BS1)</b>						Prepared: 12/20/18 Analyzed: 12/21/18					
Total Kjeldahl Nitrogen	57600	2.0	10	mg/kg	56600		102	80-120			
<b>LCS Dup (AL84169-BSD1)</b>						Prepared: 12/20/18 Analyzed: 12/21/18					
Total Kjeldahl Nitrogen	56200	2.0	10	mg/kg	56600		99.3	80-120	2.46	20	

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Arcata CA, 95521

Project Manager: Brad Finney

Reported:  
12/28/18 14:03

**Notes and Definitions**

ND	Analyte NOT DETECTED at or above the reporting limit
dry	Sample results reported on a dry weight basis
REC	Recovery
RPD	Relative Percent Difference



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## Chain of Custody - Work Order

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Lab No. 18L2248 Pg. 1 of 1

Signature below authorizes work under terms stated on reverse side.

Report to		Invoice to (if different)		Project Information		Analysis Request		TAT		Temp upon Receipt °C				
Company:		Contact:		Project ID:		Signature below authorizes work under terms stated on reverse side.	Analysis Request	Standard 10 days <input checked="" type="radio"/> RUSH: 5 days 48 hours Other: _____ days	Standard 10 days <input checked="" type="radio"/> Lab preapproval required	Ukiah temp: <u>3.2</u>	Dublin temp:	Elk Grove temp:		
Attn:		Email address:		Project No:										
Address:		Address:		PO Number:										
Humboldt State University														
Brad Finney														
Environmental Resources & Engineering														
1 Harpst Street, Arcata CA 95521														
Phone/Fax:														
707-826-3918														
Email Address:														
brad.finney@humboldt.edu														
Field Sampler - Printed Name & Signature:													Sample Notes or CDPH Source Numbers:	
Sample Identification		Sampling		Container		Preservative		Matrix		Total Number of Containers per Sample ID		TKN		
PE. 1.1		Date: 12/17 Time: 12:00		40ml Vial		Poly		X		X		X		
PE. 1.2		Date: 12/17 Time: 12:00		Glass		Sleeve		X		X		X		
PE. 1.3		Date: 12/17 Time: 12:00		Other		HCl		X		X		X		
PE. 3		Date: 12/17 Time: 12:00		HNO3		H2SO4		X		X		X		
PE. 4.1		Date: 12/17 Time: 12:00		Other		None		X		X		X		
PE. 4.2		Date: 12/17 Time: 12:00		Water		X		X		X		X		
PE. 4.3		Date: 12/17 Time: 12:00		Soil		X		X		X		X		
		Date: 12/17 Time: 12:00		Other		X		X		X		X		
Relinquished by													CDPH Write On EDT Transmission? <input type="radio"/> Yes <input checked="" type="radio"/> No	
UPS Ground via AAL acct # 894250		Date: 12-17-18		Time: 0910		Received by		Date: 12-18-18		Time: 0910		State System Number:		
												If "Y" please enter the Source Number(s) in the column above		
												CA Geotracker EDF Report?		
												Global ID: <input type="radio"/> Yes <input checked="" type="radio"/> No		
												EDF to (Email Address):		
												Sampling Company Log Code:		
												Travel and Site Time:		
												Misc. Supplies:		



*Alpha*

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20 February 2019

Humboldt State Univ - Env. Resources & Engineering  
Attn: Brad Finney  
1 Harpst Street  
Arcata, CA 95521

Enclosed are the results of analyses for samples received by the laboratory on 02/07/19 10:00. If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Jeanette L. Poplin For David S. Pingatore  
Project Manager



**alpha**

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Humboldt State Univ - Env. Resources & Engineerin 1 Harpst Street Arcata CA, 95521	Project Manager: Brad Finney	Reported: 02/20/19 09:58
--	------------------------------	-----------------------------

**Bucket 1**

**19B1043-01(Water)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Anions by EPA Method 300.0											
Nitrite as NO2	ND		1.0	mg/L	I	AB93263	02/12/19 11:48	02/12/19 11:48	EPA 300.0		T-02

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**Bucket 2**

**19B1043-02(Water)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Anions by EPA Method 300.0											
Nitrite as NO2	ND		1.0	mg/L	1	AB93263	02/12/19 12:21	02/12/19 12:21	EPA 300.0		T-02

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**Bucket 3**

**19B1043-03(Water)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Anions by EPA Method 300.0											
Nitrite as NO2	ND		1.0	mg/L	1	AB93263	02/12/19 12:53	02/12/19 12:53	EPA 300.0		T-02

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**Bucket 4**

**19B1043-04(Water)**

Analyte	Result	MDL	Reporting		Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
			Limit								
Anions by EPA Method 300.0											
Nitrite as NO2	ND		1.0	mg/L	1	AB93263	02/12/19 13:10	02/12/19 13:10	EPA 300.0		T-02

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--	------------------------------	-----------------------------

### Anions by EPA Method 300.0 - Quality Control

Analyte	Result	MDL	Reporting Limit	Units	Spike Level	Source Result	%REC Limits	RPD	RPD Limit	Notes
<b>Batch AB93263 - General Preparation</b>										
<b>Blank (AB93263-BLK1)</b>					Prepared & Analyzed: 02/12/19					
Nitrite as NO2	ND		1.0	mg/L						
<b>LCS (AB93263-BS1)</b>					Prepared & Analyzed: 02/12/19					
Nitrite as NO2	18.3		1.0	mg/L	18.2		101	90-110		
<b>Duplicate (AB93263-DUP1)</b>					Source: 19B0259-16 Prepared & Analyzed: 02/12/19					
Nitrite as NO2	ND		1.0	mg/L	ND			20		
<b>Matrix Spike (AB93263-MS1)</b>					Source: 19B0259-16 Prepared & Analyzed: 02/12/19					
Nitrite as NO2	18.0		5.0	mg/L	18.2	ND	98.7	80-120		
<b>Matrix Spike (AB93263-MS2)</b>					Source: 19B0559-01 Prepared & Analyzed: 02/12/19					
Nitrite as NO2	17.5		5.0	mg/L	18.2	ND	96.0	80-120		
<b>Matrix Spike Dup (AB93263-MSD1)</b>					Source: 19B0259-16 Prepared & Analyzed: 02/12/19					
Nitrite as NO2	18.0		5.0	mg/L	18.2	ND	98.6	80-120	0.102	20

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[illegible]

## Appendix C - Raw Data from Spatial Characterization

Table C-1. Raw 2018 Survey Data.

Point	Longitude	Latitude	Total Depth (ft)	OPBS Depth (ft)	Ratio
1	-124.08529	40.85015	2.15	1.92	0.89
2	-124.08533	40.85003	2.28	1.95	0.86
3	-124.08533	40.8503	3.73	2.7	0.72
4	-124.08539	40.85038	1.8	1.72	0.96
5	-124.08546	40.85045	3.7	0.1	0.03
6	-124.08552	40.85053	2.52	1.8	0.71
7	-124.08564	40.85061	4.35	2.5	0.57
8	-124.08564	40.85067	3.38	3.21	0.95
9	-124.08576	40.85076	2.8	1.9	0.68
10	-124.08584	40.85082	4.4	2.8	0.64
11	-124.08604	40.85089	4.5	3	0.67
12	-124.08601	40.85097	4.7	0.7	0.15
13	-124.0861	40.85104	7.75	0.65	0.08
14	-124.08622	40.85119	5.9	3.2	0.54
15	-124.08637	40.85122	6.8	4.6	0.68
16	-124.08651	40.85127	6	3.7	0.62
17	-124.08532	40.85004	3.1	2.4	0.77
18	-124.08539	40.85012	4.1	2.5	0.61
19	-124.08545	40.85021	4.6	2.3	0.50
20	-124.08552	40.85029	6.2	2.95	0.48
21	-124.08559	40.85038	5.8	2.5	0.43
22	-124.08565	40.85047	5.8	3.2	0.55
23	-124.08572	40.85055	5.9	2.7	0.46
24	-124.08579	40.85064	5.65	2.4	0.42
25	-124.08585	40.85072	5.6	2.2	0.39
26	-124.08592	40.85081	6.2	2.5	0.40
27	-124.08599	40.8509	5.5	2.8	0.51
28	-124.08605	40.85098	6.4	4.4	0.69
29	-124.08612	40.85107	5.4	0.4	0.07
30	-124.08626	40.85118	5.9	3	0.51
31	-124.08642	40.85119	5.1	3	0.59
32	-124.08542	40.84991	2.55	2.55	1.00

<b>Point</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Total Depth (ft)</b>	<b>OPBS Depth (ft)</b>	<b>Ratio</b>
33	-124.08542	40.85	6	3.6	0.60
34	-124.08555	40.85009	6.45	3.05	0.47
35	-124.08562	40.85019	6	3.63	0.61
36	-124.08569	40.85028	5.3	3.4	0.64
37	-124.08575	40.85038	5.3	3.32	0.63
38	-124.08582	40.85047	5.05	3.45	0.68
39	-124.08589	40.85056	5.75	2.65	0.46
40	-124.08596	40.85066	5.54	2.49	0.45
41	-124.08602	40.85075	6.18	3	0.49
42	-124.08609	40.85085	6.1	3.53	0.58
43	-124.08616	40.85094	6.7	1.75	0.26
44	-124.08623	40.85103	7	3.08	0.44
45	-124.08629	40.85113	6.05	3.78	0.62
46	-124.08554	40.84974	3	2.6	0.87
47	-124.08554	40.84981	4.4	3.35	0.76
48	-124.08561	40.84991	5.9	2.73	0.46
49	-124.08567	40.85001	7.2	3.11	0.43
50	-124.08574	40.85011	4.5	2.33	0.52
51	-124.08581	40.85021	4.45	2.59	0.58
52	-124.08587	40.85031	5	2.73	0.55
53	-124.08594	40.85041	4.55	2.78	0.61
54	-124.08601	40.85051	4.48	2	0.45
55	-124.08607	40.85061	4.45	1.9	0.43
56	-124.08614	40.85071	4.55	1.93	0.42
57	-124.08621	40.85081	4.6	2.03	0.44
58	-124.08627	40.85091	5	2	0.40
59	-124.08634	40.85101	6.45	2.67	0.41
60	-124.08641	40.85111	6.44	2.65	0.41
61	-124.08647	40.85121	7.2	4.84	0.67
62	-124.08565	40.84971	3.04	1.95	0.64
63	-124.08571	40.84977	5.4	2.5	0.46
64	-124.08577	40.84986	6.3	2.25	0.36
65	-124.08665	40.85124	4.75	2.8	0.59
66	-124.08576	40.84964	1.8	1.11	0.62
67	-124.0858	40.8497	4.85	4.13	0.85
68	-124.08595	40.84992	8.2	6.3	0.77

Point	Longitude	Latitude	Total Depth (ft)	OPBS Depth (ft)	Ratio
69	-124.08607	40.85015	4.7	1.9	0.40
70	-124.0862	40.85032	4.65	1.65	0.35
71	-124.08632	40.8505	4.6	1.15	0.25
72	-124.08642	40.85073	4.65	1.75	0.38
73	-124.08673	40.85114	4.65	1.9	0.41
74	-124.086754	40.85126	5.5	3.5	0.64
75	-124.085908	40.84963	2.15	1.25	0.58
76	- 124.0868586	40.85123	2.4	1.2	0.50
77	- 124.0860481	40.84964	1.91	0.6	0.31
78	-124.0861	40.84974	6.3	4.05	0.64
79	-124.0862	40.84994	5.6	3.05	0.54
80	-124.086457	40.85031708	4.8	0.95	0.20
81	-124.08636	40.8501	4.7	1.4	0.30
82	- 124.0865738	40.85054	4.8	1.4	0.29
83	-124.0867	40.85074	4.75	1.7	0.36
84	- 124.0868075	40.85093	4.75	1.55	0.33
85	- 124.0869827	40.85122	2.46	1.2	0.49
86	- 124.0862072	40.84963	2.15	1.25	0.58
87	-124.087072	40.85129	1.43	0.43	0.30
88	- 124.0863432	40.84964	1.94	0.5	0.26
89	- 124.0863957	40.84969	4.85	2.9	0.60
90	-124.08647	40.84989	6.6	3.3	0.50
91	-124.08663	40.85010942	5	0.95	0.19
92	- 124.0867112	40.85030529	5.1	0.8	0.16
93	- 124.0868163	40.85050116	4.8	1.52	0.32
94	- 124.0869215	40.85069703	6.25	1.55	0.25
95	-124.08701	40.8509	4.8	1.52	0.32

Point	Longitude	Latitude	Total Depth (ft)	OPBS Depth (ft)	Ratio
96	-124.08708	40.85111	5.13	2.12	0.41
97	-124.086503	40.84964	2.25	0.55	0.24
98	-124.087285	40.85117	2.56	1.5	0.59
99	- 124.0866506	40.84967	1.9	0.4	0.21
100	-124.08665	40.84977	7	3.5	0.50
101	- 124.0867891	40.84993664	5.25	1.55	0.30
102	-124.08689	40.8501	6.4	0.92	0.14
103	-124.08699	40.85024	4.84	1.3	0.27
104	-124.0871	40.8505	4.8	1.6	0.33
105	-124.08717	40.85066	4.95	1.65	0.33
106	-124.08722	40.85084	4.8	1.75	0.36
107	- 124.0873433	40.85105064	4.8	1.6	0.33
108	- 124.0873895	40.85116	2.7	1.15	0.43
109	- 124.0868022	40.84972	4.24	2.6	0.61
110	-124.08688	40.84982	2.7	0	0.00
111	- 124.0874905	40.85118	1.25	0	0.00
112	-124.086918	40.84969	1.55	0.53	0.34
113	-124.08703	40.84983	7.4	2	0.27
114	- 124.0870442	40.84990456	5.45	1.2	0.22
115	- 124.0871704	40.85018594	4.8	1.05	0.22
116	- 124.0872967	40.85046732	4.8	1.2	0.25
117	- 124.0873387	40.85056112	4.83	1.22	0.25
118	-124.08735	40.85065491	4.9	1.7	0.35
119	-124.087465	40.8508425	4.87	1.75	0.36
120	-124.087507	40.85093629	4.95	1.75	0.35
121	- 124.0875491	40.85103009	4.87	1.95	0.40
122	- 124.0875912	40.85115	1.4	0	0.00



<b>Point</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Total Depth (ft)</b>	<b>OPBS Depth (ft)</b>	<b>Ratio</b>
123	- 124.0870383	40.8496132	1.93	0.63	0.33
124	- 124.0870793	40.84970589	5.4	2.16	0.40
125	- 124.0871204	40.84979859	5.55	1.3	0.23
126	- 124.0871615	40.84989129	5.9	1.42	0.24
127	- 124.0872026	40.84998399	4.9	1.15	0.23
128	- 124.0872437	40.85007668	4.9	1.1	0.22
129	- 124.0873669	40.85035477	4.9	1.3	0.27
130	- 124.0874491	40.85054017	4.85	1.33	0.27
131	- 124.0874902	40.85063287	4.89	1.33	0.27
132	- 124.0876134	40.85091096	4.9	1.45	0.30
133	- 124.0876545	40.85100365	4.75	1.42	0.30
134	- 124.0876956	40.85112	2.54	1.3	0.51
135	- 124.0871865	40.84965	1.95	0.49	0.25
136	- 124.0873418	40.85000701	4.9	1.2	0.24
137	-124.08751	40.85036092	4.9	1.17	0.24
138	- 124.0876136	40.85062636	4.9	1.25	0.26
139	- 124.0876913	40.85080331	4.9	1.3	0.27
140	- 124.0877301	40.85089179	4.8	1.3	0.27
141	- 124.0877689	40.85098027	4.85	1.75	0.36
142	- 124.0878078	40.8511	3.7	1.63	0.44
143	- 124.0873106	40.8497	4.18	0.95	0.23

<b>Point</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Total Depth (ft)</b>	<b>OPBS Depth (ft)</b>	<b>Ratio</b>
144	- 124.0873487	40.84972861	6.1	1.72	0.28
145	- 124.0873868	40.84981709	6.4	1.4	0.22
146	- 124.0874249	40.84990558	5.65	1.06	0.19
147	-124.087463	40.84999407	5.05	0.5	0.10
148	- 124.0875011	40.85008255	5	0.8	0.16
149	- 124.0875392	40.85017104	5.05	0.75	0.15
150	- 124.0875773	40.85025952	4.95	0.85	0.17
151	- 124.0876154	40.85034801	4.86	1.03	0.21
152	- 124.0876535	40.85043649	4.9	1.15	0.23
153	- 124.0876916	40.85052498	4.92	1.14	0.23
154	- 124.0877297	40.85061347	4.96	1.23	0.25
155	-124.08774	40.85070195	4.98	1.3	0.26
156	- 124.0878059	40.85079044	4.9	1.32	0.27
157	-124.08787	40.85088	4.85	1.35	0.28
158	-124.08785	40.85099	4.85	1.6	0.33
159	-124.0879	40.85109	3.74	1.95	0.52
160	-124.08768	40.8496	2.25	0.1	0.04
161	-124.087727	40.84973633	7.8	2.53	0.32
162	-124.08782	40.84991	5.25	0.68	0.13
163	- 124.0878833	40.85009669	5.25	0.61	0.12
164	- 124.0879614	40.85027687	5.1	0.9	0.18
165	- 124.0880395	40.85045706	5.3	1.06	0.20
166	- 124.0881177	40.85063724	5.1	1.23	0.24
167	- 124.0881958	40.85081742	5.2	1.77	0.34

Point	Longitude	Latitude	Total Depth (ft)	OPBS Depth (ft)	Ratio
168	-124.088274	40.85099761	5.1	2.68	0.53
169	-124.088005	40.84951338	5.8	0.6	0.10
170	- 124.0880459	40.84960803	7.6	1.95	0.26
171	- 124.0881276	40.84979734	5.1	0.35	0.07
172	-124.08823	40.84998	6.85	1	0.15
173	- 124.0882911	40.85017595	5.2	0.92	0.18
174	- 124.0883729	40.85036526	5.8	0.96	0.17
175	- 124.0884547	40.85055457	5.4	1.05	0.19
176	- 124.0885364	40.85074388	5.25	1.5	0.29
177	- 124.0886182	40.85093318	5.1	2	0.39
178	- 124.0886516	40.8492959	4.8	0.42	0.09
179	- 124.0886963	40.84939841	8.1	2.11	0.26
180	- 124.0887856	40.84960344	5.4	0.54	0.10
181	- 124.0888748	40.84980846	5.4	0.42	0.08
182	- 124.0889641	40.85001349	5.4	0.55	0.10
183	- 124.0890534	40.85021851	5.5	0.1	0.02
184	- 124.0891427	40.85042354	5.4	1.06	0.20
185	-124.089242	40.85062	5.3	1.63	0.31
186	- 124.0893213	40.85083359	5	2.08	0.42
187	- 124.0893512	40.84916275	4.55	0.48	0.11
188	-124.089396	40.84926623	7.4	2.73	0.37
189	-124.08947	40.84946	5.5	2.18	0.40
190	-124.08957	40.84969	5.3	2.31	0.44

<b>Point</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Total Depth (ft)</b>	<b>OPBS Depth (ft)</b>	<b>Ratio</b>
191	- 124.0896651	40.8498871	5.55	2.2	0.40
192	- 124.0897549	40.85009406	5.4	1.3	0.24
193	- 124.0898446	40.85030102	5.4	0.43	0.08
194	- 124.0899343	40.85050797	5.65	1.17	0.21
195	-124.090024	40.85071493	5	2.05	0.41
196	-124.08997	40.84894	3.65	0.95	0.26
197	- 124.0900781	40.84910198	8.25	3.73	0.45
198	-124.09016	40.84934	5.4	2.34	0.43
199	- 124.0902648	40.84953668	5.4	2.41	0.45
200	- 124.0903581	40.84975403	5.4	2.49	0.46
201	- 124.0904514	40.84997138	5.4	2.34	0.43
202	- 124.0905447	40.8502	5.4	2	0.37
203	-124.090638	40.85040608	5.4	2.02	0.37
204	- 124.0907313	40.85062343	4.8	1.61	0.34
205	-124.09029	40.84885	3.61	0.45	0.12
206	- 124.0903962	40.84898	7.7	3.32	0.43
207	-124.09048	40.84924	8.5	3.35	0.39
208	- 124.0905868	40.84943606	5.45	2.39	0.44
209	- 124.0906821	40.8497	5.45	2.63	0.48
210	- 124.0907774	40.8498752	6	4.18	0.70
211	- 124.0908727	40.85009476	5.4	2.54	0.47
212	-124.09098	40.85033	5.4	2.57	0.48
213	- 124.0910634	40.85053389	6.75	4.65	0.69

Point	Longitude	Latitude	Total Depth (ft)	OPBS Depth (ft)	Ratio
214	- 124.0905517	40.84879	3.16	0.35	0.11
215	-124.09063	40.84897	8.8	2.64	0.30
216	-124.09072	40.8492	8.15	3.18	0.39
217	-124.09082	40.84941549	5.65	2.49	0.44
218	-124.09092	40.84962	8.55	4.9	0.57
219	- 124.0910208	40.84985241	8.15	4.17	0.51
220	- 124.0911146	40.85007088	8.3	3.61	0.43
221	- 124.0912085	40.85028934	7.85	3.83	0.49
222	- 124.0913023	40.8505078	8.8	6.74	0.77
223	-124.09089	40.84887	3.33	0.72	0.22
224	-124.09093	40.84892	6.5	3.31	0.51
225	-124.09096	40.84904	8.8	3.83	0.44
226	- 124.0910232	40.84922339	8.1	2.3	0.28
227	-124.0911	40.84943	8.8	2.91	0.33
228	-124.09119	40.84966	7.81	3.26	0.42
229	-124.09123	40.84983	7.81	3.54	0.45
230	-124.0913	40.85006	7.85	4.05	0.52
231	-124.09135	40.85023	7.75	3.63	0.47
232	-124.09138	40.85035	7.85	4.25	0.54
233	-124.0914	40.85044	7.95	4.62	0.58
234	-124.09103	40.84907	9.35	4.35	0.47
235	-124.09103	40.84908	10	5	0.50
236	-124.09108	40.8493	11.6	5.8	0.50
237	-124.09119	40.84953	11.26	5.36	0.48
238	-124.09122	40.84974	10.93	6.63	0.61
239	-124.09109	40.84987	11.9	7.9	0.66
240	-124.09113	40.84999	11.1	7.1	0.64
241	-124.09133	40.85015	10.6	6.6	0.62
242	-124.09121	40.85025	11.2	9.2	0.82
243	-124.09119	40.85035	11.2	8.2	0.73
244	-124.09121	40.85046	11.1	7.8	0.70

<b>Point</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Total Depth (ft)</b>	<b>OPBS Depth (ft)</b>	<b>Ratio</b>
245	-124.09135	40.8504	11.4	8.1	0.71
246	-124.09145	40.85036	10.6	7.6	0.72
247	-124.09051	40.84895	12.4	8.4	0.68
248	-124.09014	40.84914	10.8	6.8	0.63
249	-124.08981	40.84916	10.6	5.6	0.53
250	-124.08959	40.84929	9.3	4.3	0.46
251	-124.08923	40.84943	8.6	5.1	0.59
252	-124.08919	40.8494	10.1	6.1	0.60
253	-124.08915	40.84931	9.3	5.3	0.57

## Appendix D - Data from Biogeochemical Characterization

Table D-1. Data from biogeochemical characterization.

Sample	Estimated Density (g/mL)	Moisture Content (%)	Volatile Solids (g Volatile/g Dried Sample)	TKN (mg/kg)	NH <sub>3</sub> -N (mg/kg)	NO <sub>3</sub> -N (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	COD (mg/kg)
1.1	0.9718	0.9587	0.6021	43,621.04	3,895.30	14.49	104,694.37	48,530.83	713,424.44
1.2	0.8404	0.9186	0.4710	33,177.34	6,850.12	8.20	53,221.53	27,870.93	609,005.37
1.3	0.8501	0.8688	0.3503	23,622.44	4,772.03	7.81	25,330.58	18,518.17	396,898.49
2.1	0.9360	0.9616	0.5444		6,382.33	16.49	62,869.02	41,066.21	598,162.51
2.2	0.9047	0.8939	0.3517		4,927.06	6.82	22,801.16	21,160.49	342,354.87
2.3	0.7362	0.8590	0.3617		4,394.01	25.41	22,420.06	17,357.72	333,727.19
3	0.9423	0.9309	0.2945	21,705.78	1,559.02	13.85	55,395.48	31,692.76	304,417.22
4.1	0.9423	0.9611	0.5181	35,974.80	4,354.99	19.25	98,523.66	38,161.55	567,519.82
4.2	0.8316	0.9209	0.3924	24,034.85	3,404.62	11.71	29,147.44	22,999.58	399,539.47
4.3	0.9096	0.8779	0.2862	17,199.76	2,472.65	8.91	16,562.23	16,267.37	332,183.82
5.1	0.9993	0.9587	0.4349		3,674.94	20.51	59,378.18	30,235.03	493,120.96
5.2	0.8682	0.9108	0.3196		3,141.68	11.60	25,708.51	22,141.87	367,091.34
5.3	0.8846	0.9183	0.5198		4,469.43	26.00	23,656.28	17,632.51	555,499.42

## Appendix E - Raw Data from Treatment Experiments

Table E-1. Data from treatment characterization.

<b>Trial</b>	<b>Date</b>	<b>Moisture (%)</b>	<b>Density (kg/L)</b>	<b>Volatile Solids (mg/kg Dried Sample)</b>	<b>COD (mg/kg)</b>	<b>BOD (mg/kg)</b>	<b>CBOD (mg/kg)</b>	<b>SBOD (mg/kg)</b>	<b>NH<sub>3</sub>-N (mg/kg)</b>	<b>NO<sub>3</sub>-N (mg/kg)</b>	<b>Temp (°C)</b>	<b>pH</b>	<b>DO (mg/L)</b>
Trial I	9/23/18				1.16E+06	2.52E+05	5.92E+04	2.68E+04	3,319	146	20.6		0.41
	9/24/18	99.1%	0.971	5.99E+05					2,469	148	15.7		3.22
	9/25/18								1,755	182	19.5		0.6
	9/26/18	99.1%	0.999	5.96E+05	1.02E+06				608	853			3.55
	9/27/18								865	189	16.8		5.83
	9/28/18	99.0%	0.993	5.84E+05	1.03E+06				495	928	16.3		7.04
	10/1/18	99.1%	0.981	5.75E+05	9.27E+05	2.45E+05	4.65E+04	1.48E+04	303	2,149	17		6.33
	10/2/18								267	2,780			
	10/3/18				9.75E+05				537	3,110	17.9		5.47
	10/4/18								479	3,361	18.1		6.22
	10/5/18				9.84E+05								
	10/11/18								2,357	4,396	16.1		7.32
	10/12/18								2,146	4,309			



Trial	Date	Moistur e (%)	Densit y (kg/L)	Volatile Solids (mg/kg Dried Sample)	COD (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	SBOD (mg/ kg)	NH3-N (mg/kg )	NO3-N (mg/kg )	Tem p (°C)	pH	DO (mg/L )
Trial 2	10/13/18	99.0%	0.966	5.89E+05	1.36E+06	1.51E+05	1.42E+04	1.69E+04	7,727	148	18	7.6	9.15
	10/15/18								6,746	100		7.8	
	10/16/18				1.02E+06				5,593	167		7.1	
	10/17/18				1.03E+06				4,989	441			
	10/22/18								5,925	2,204			
	10/24/18	99.2%	0.992	6.04E+05		1.08E+05	1.41E+04	4.64E+03	4,233	3,269			
	10/25/18								3,282	3,709			
	10/29/18								4,077	4,341			
	10/31/18								5,651	4,720			
	11/7/18								9,247	6,207			
	11/9/18	99.2%	0.995	5.95E+05		8.52E+04	1.16E+04	3.39E+03					
	11/10/18								9,975	7,404			
	11/16/18								9,283	8,624			
	11/20/18	99.2%	0.979		7.58E+05				6,721	8,264			
	11/21/18								7,142	8,432			

[illegible]

Trial	Date	Moisture (%)	Density (kg/L)	Volatile Solids (mg/kg Dried Sample)	COD (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	SBOD (mg/kg)	NH <sub>3</sub> -N (mg/kg)	NO <sub>3</sub> -N (mg/kg)	Temp (°C)	pH	DO (mg/L)
	1/25/19								6	6,016	10.5	7.34	10.02
	1/28/19								44	5,180		7.08	
	1/29/19								6	5,781		7	
	1/30/19								8	5,472	12	7.14	9.46
	1/31/19								16	5,956			
	2/1/19			5.01E+05					2	6,168			
	2/5/19										8.4	6.95	
	2/6/19								8	5,018	8.3	6.91	
	2/7/19										7.8	6.89	
	2/8/19								10	4,848	8.8	6.89	10.91
	2/11/19										7.8	6.89	11.26
	2/13/19								6	5,180	10		
	2/14/19								8	5,273	11.4		
	2/15/19								7	4,896			
	2/22/19					9.11E+04	9.70E+03	2.01E+03	19	6,162			

Trial	Date	Moisture (%)	Density (kg/L)	Volatile Solids (mg/kg Dried Sample)	COD (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	SBOD (mg/kg)	NH3-N (mg/kg)	NO3-N (mg/kg)	Temp (°C)	pH	DO (mg/L)
Trial 4	1/10/19	99.0%	0.984	4.35E+05		8.10E+04	2.47E+04	1.35E+04	5,384	81			
	1/11/19	99.0%	0.989	4.44E+05		7.86E+04	2.21E+04	1.23E+04	5,427	108	11.7	8.05	
	1/14/19								5,716	262	11	8.01	
	1/15/19								3,452	389		7.59	
	1/16/19								4,733	473	12.6	7.58	9.55
	1/17/19											7.59	
	1/18/19	99.1%	0.999	4.67E+05		1.03E+05	1.82E+04	4.25E+03	4,595	990	10.7	7.06	10.23
	1/21/19								2,287	2,597	11.7	5.76	
	1/22/19								1,050	2,955	9.9	7.09	
	1/23/19								85	3,513		7.37	
	1/24/19											7.48	
	1/25/19								6	5,711	10.3	7.52	11.15
	1/28/19								49	5,338		7.32	
	1/29/19								11	5,638		7.28	
	1/30/19								7	5,583	11.8	7.4	10.36

Trial	Date	Moisture (%)	Density (kg/L)	Volatile Solids (mg/kg Dried Sample)	COD (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	SBOD (mg/kg)	NH3-N (mg/kg)	NO3-N (mg/kg)	Temp (°C)	pH	DO (mg/L)
	1/31/19			4.81E+05					17	6,016			
	2/1/19								2	6,613			
	2/5/19										7.4	7.28	
	2/6/19								13	4,944	8	7.22	
	2/7/19										7.3	7.23	
	2/8/19								10	4,712	8.7	7.24	11.77
	2/11/19										7	7.22	12.25
	2/13/19								6	4,953	9.8		
	2/14/19								8	5,028	11.5		
	2/15/19								5	4,823			
	2/22/19					8.42E+04	1.08E+04	1.67E+03	10	5,774			
Trial 5	3/1/19	98.7%	0.988	4.07E+05	2.19E+05	2.02E+05	3.92E+04	9.83E+03	6,170	140			
	3/4/19				1.51E+05	2.00E+05	3.95E+04	9.80E+03	5,113	648		7.8	
	3/5/19								4,177	800		7.3	
	3/7/19					7.86E+04			3,047	1,443	9.4	7.5	8.93
	3/8/19								2,742	1,496			
	3/12/19								35	3,512		7.2	

Trial	Date	Moistur e (%)	Densit y (kg/L)	Volatile Solids (mg/kg Dried Sample)	COD (mg/kg)	BOD (mg/kg)	CBOD (mg/kg)	SBOD (mg/ kg)	NH3-N (mg/kg )	NO3-N (mg/kg )	Tem p (°C)	pH	DO (mg/L )				
	3/13/19	99.3%	0.982	5.36E+0 5		6.77E+0 4	1.58E+0 4	2.42E+0 3	13	2,975	12.8	9.1	7.1				
	3/14/19								13	3,462				7.1			
	3/15/19														7.2		
	3/18/19																
	3/20/19								16	3,320				9		6,092	
	3/26/19														9		4,786
	4/5/19																
	4/10/19																
Trial 6	3/1/19	98.9%	0.987	4.39E+0 5	1.84E+0 5	1.98E+0 5	3.85E+0 4	9.74E+0 3	6,607	141	9.1	7.8	10				
	3/4/19				1.75E+0 5	1.97E+0 5	3.86E+0 4	9.69E+0 3	6,041	368							
	3/5/19				7.91E+0 4				5,033	397				7.6			
	3/7/19								4,203	706				7.8			
	3/8/19								4,014	670				7.2			
	3/12/19								2,253	2,299							
	3/13/19								1,083	2,315							
	3/14/19								13	3,499				8.8	6.7		
	3/15/19														7.2		
	3/18/19														7.2		

<b>Trial</b>	<b>Date</b>	<b>Moisture (%)</b>	<b>Density (kg/L)</b>	<b>Volatile Solids (mg/kg Dried Sample)</b>	<b>COD (mg/kg)</b>	<b>BOD (mg/kg)</b>	<b>CBOD (mg/kg)</b>	<b>SBOD (mg/kg)</b>	<b>NH<sub>3</sub>-N (mg/kg)</b>	<b>NO<sub>3</sub>-N (mg/kg)</b>	<b>Temp (°C)</b>	<b>pH</b>	<b>DO (mg/L)</b>
	3/20/19	99.1%	0.985	5.15E+05							12.8		
	3/26/19					6.96E+04	1.73E+04	1.96E+03	10	3,756			
	4/5/19								8	4,070			
	4/10/19				1.64E+05				11	4,678			